PTI Journal *Case Study*

SUSTAINABILITY AND POST-TENSIONED CONCRETE: GRAY IS THE NEW GREEN

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INTRODUCTION

The environmental impact of a building can be managed in many ways: while a large part is achieved through efficient operation and maintenance, it is creative layout and design that ultimately take full advantage of building green. Considerable improvements in efficiency can be realized by focusing on a building's basic structural frame design and layout. For example, the use of post-tensioning can reduce foundation, column, wall and slab sizes, floor-to-floor height, and decrease site shoring/ground excavation requirements. In high seismic regions, post-tensioning provides the added benefit of reduced seismic forces and material demand due to lower seismic mass. Moreover, many nonstructural elements in post-tensioned buildings benefit from reduced floor-to-floor height, such as mechanical, electrical, and plumbing systems; exterior cladding; vertical transportation systems; and interior architectural features.

The most recognized green building rating system in the U.S. was developed by the United States Green Building Council (USGBC), known as Leadership in Energy and Environmental Design (LEED®). For new construction (LEED®-NC), the rating system currently offers four certification levels that are awarded based on points earned in each of six categories. More information regarding the LEED® rating system can be found at **www.usgbc.org**.

The LEED®-NC system, in its current form, concentrates heavily on architectural and mechanical systems due to its derivation from energy program initiatives. A building's basic structural frame, however, can still contribute points through two of the six LEED®-NC categories: materials and resources, and innovation and design. Despite the limited contribution of the basic structural frame for LEED® certification, a well-developed building layout can lead to substantial material reductions that, while not directly addressed by LEED®, lie at the true core of building green.

Fig. 1—2201 Westlake, Seattle, WA. (Photo courtesy of Callison Architecture.)

The following case study will provide examples of how the use of post-tensioning provided a highly efficient structural system that significantly reduced materials and construction cost while also offering noteworthy contributions to overall occupant health and comfort.

CASE STUDY: 2201 WESTLAKE, SEATTLE, WA

2201 Westlake (Fig. 1) is a two-tower 450,000 ft^2 (42,000 m^2) post-tensioned cast-in-place concrete mixed-use development recently constructed in the South Lake Union in downtown Seattle, WA. With a seven-story office building and a 14-story office/condominium tower over a five-level podium, 2201 Westlake is receiving wide market acceptance. A five-level underground garage provides parking for both residential and nonresidential users. The ground floor offers 21,000 ft^2 (1950 m^2) of retail/restaurant space with a reconfigured street intersection along its north side. This creates a generous pedestrian area complete with colored concrete sidewalks, art features, bike racks, and large planted areas.

Fig. 2—Open office space available with post-tensioning. (Photography by Larry Gill.)

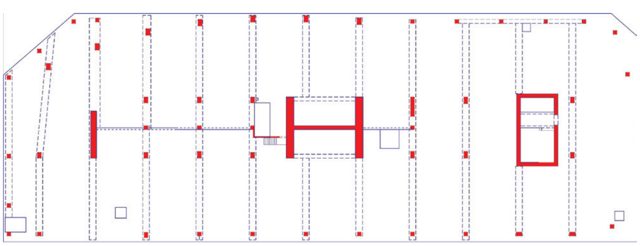

Fig. 3—Typical parking framing plan. (Illustration courtesy of Cary Kopczynski & Company.)

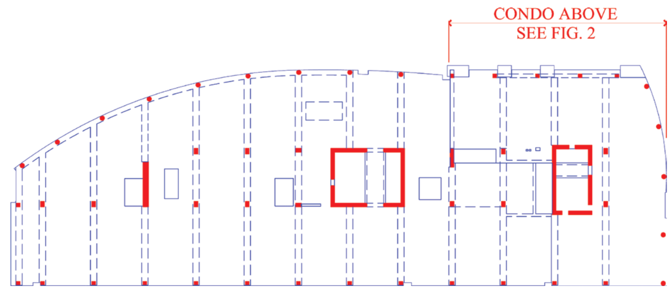

Fig. 4—Typical framing plan at office level. (Illustration courtesy of Cary Kopczynski & Company.)

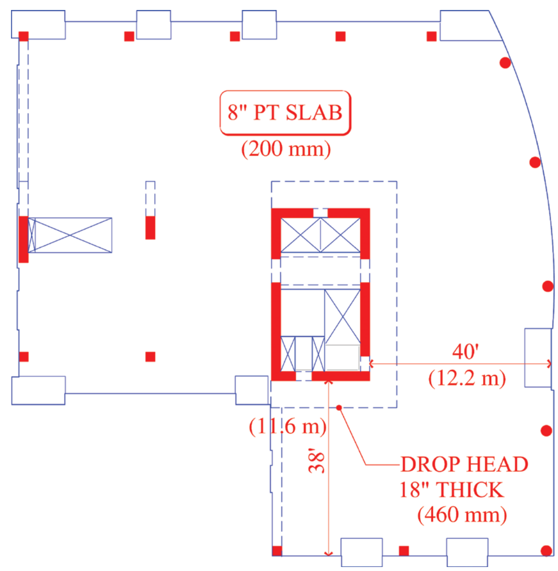

Fig. 5—Drop head framing at residential units. (Illustration courtesy of Cary Kopczynski & Company.)

The development features 300,000 ft^2 (28,000 m^2) of sustainable office space (Fig. 2), 135 luxury condominiums known as Enso, and residential amenities, such as a guest suite for overnight visitors, a roof deck with an indoor/outdoor fireplace, lounging and sunning areas, dining and entertainment areas, and a state-of-the-art exercise facility. The project has targeted LEED Silver certification for its innovative and eco-friendly design, but anticipates achieving Gold.

The architectural layout of the office tower and parking circulation below played a key role in selecting a post-tensioned slab and wide shallow beam system to minimize columns, increase spans, and provide more open space. For the garage and office framing (Fig. 3 and 4), the design uses 8 in. (200 mm) thick slabs and 42 in. (1070 mm) wide by 18 in. (460 mm) deep beams, with typical slab spans of 28 ft (8.5 m) and beam spans of 43 ft (13.1 m). The reduced floor-to-floor height and long spans at the residential tower required a much different approach as column transfers could not be accommodated (Fig. 5). The floor framing therefore employed a "drop head" technique which eliminated the need for interior columns and allowed longer floor spans and more useable living space. The drop head design involved thickening the floor slab in the corridors surrounding the stair/elevator core where the clear height was less critical. The thickened slab acted as a cantilever support off the core wall, increasing the floor span by approximately the width of the corridor. The drop head design approach borrows the ceiling space from mechnical, electrical, and plumbing (MEP) and redirects it from the corridors to the dropped ceiling within the residential unit's entryway foyer. The drop head was thickened from 8 to 18 in. (200 to 460 mm) to allow for spans up to 40 ft (12.2 m). The resulting column free space placed more of the structure's dead load on the stair/elevator core, thereby "precompressing" the core and allowing seismic overturning forces to be resisted more efficiently. The drop head design also had a positive effect throughout the remainder of the building; fewer columns meant fewer space allocation challenges and eliminated potentially intrusive transfer beams that would have competed for valuable retail and parking space at the lower levels. Fewer columns can also translate to greater occupant comfort within office and residential spaces by providing greater open space; unobstructed views; and greater flexibility with furniture, appliances, and décor arrangements (Fig. 6).

The drop head design did not come without a price. While post-tensioning quantities increased by approximately 0.25 lb/ft^2 (1.2 kg/m^2) beyond what would have been required for a conventional flat plate system, the design also cut wall reinforcing requirements by an estimated 10 to 20%. The end result was a slight overall cost increase. Benefits gained by the removal of columns far outweighed the additional cost, however.

The post-tensioned subterranean parking levels used a carefully designed concrete mixture that minimized drying shrinkage and moderate post-tensioning to mitigate the slabs' shortening tendencies. The typical 9 ft (2.7 m) floor-to-floor height created through the use of a post-tensioned system provided direct savings in reduced excavation, temporary shoring, and basement wall requirements.

When compared to a nonprestressed floor system, post-tensioning subterranean parking decks improve serviceability, shorten the construction cycle, and increase slab span capability.

The structure's lateral resistance is provided by 24 in. (610 mm) thick full-height shear walls located at the stair and elevator cores. Maintaining column and wall sizes for the full building height enhanced constructibility and condensed overall construction time. Labor costs and construction time were further reduced by eliminating the need to "puddle" high-strength concrete at columns.

The ground floor loading dock is supported by a 24 in. (610 mm) wide by 140 in. (3550 mm) deep post-tensioned girder that spans approximately 112 ft (34.1 m). In addition, the girder supports a large portion of the ground floor retail space and a parking access ramp. The loading dock was designed for a nonreducible live load of 250 psf (12.0 kPa) and an added dead load of 100 psf (4.8 kPa). The ground floor retail was designed for a reducible live load of 225 psf

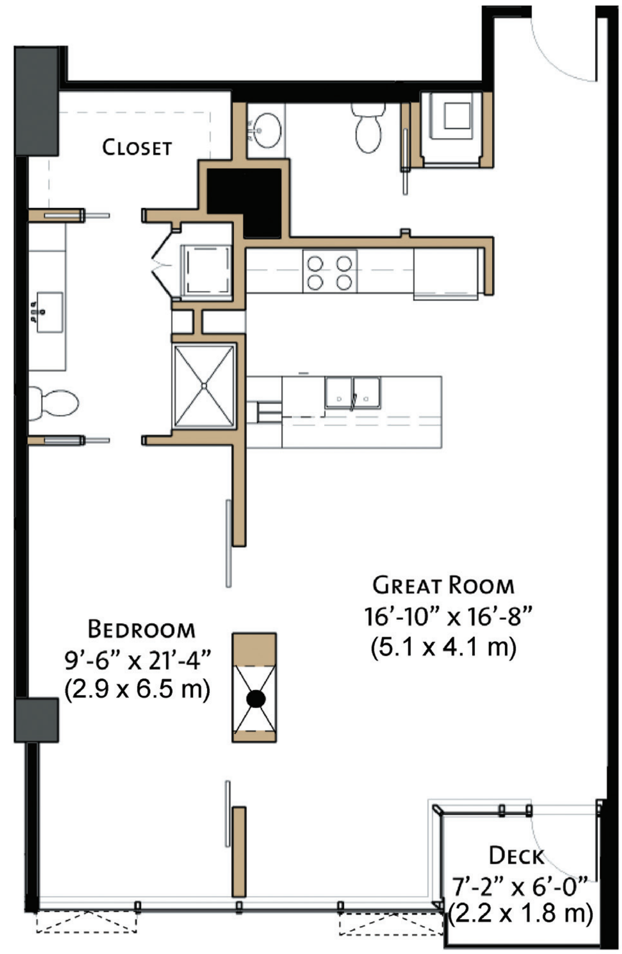

Fig. 6—Interior view of unit. (Illustration courtesy of Vulcan Inc. and Cary Kopczynski & Company.)

(10.8 kPa) and an added dead load of 75 psf (3.6 kPa) in anticipation of future storage mezzanines. The girder length and loading requirements made post-tensioning the only viable choice to provide adequate support and keep long-term deflections within acceptable limits.

The post-tensioned slabs were specified with a compressive strength of 6000 psi (41 MPa) at 56 days. In addition, a minimum slab compressive strength of 3000 psi (21 MPa) at 3 days was specified for early stressing purposes. The slab concrete strength was compatible with the high-strength concrete at the columns such that the column design remained unaffected.

The office tower is supported by mat foundations at the stair and elevator cores. The foundations are tied to the perimeter walls to resist overturning and minimize settlements. The residential tower is also supported by a mat foundation but covers the full tower footprint. To reduce concrete volume and temporary shoring depth, the bottom of the mat was

Fig. 7—Construction of mat foundation. (Photo courtesy of Cary Kopczynski & Company.)

tapered from 7 ft (2.1 m) at the center to 5 ft (1.5 m) along the perimeter (Fig. 7).

Cast-in-place post-tensioned concrete provided multiple framing options during conceptual design, particularly with column coordination between the parking levels and office space above. For most urban developments, parking layout plays a pivotal role in determining the fate of a proposed building—if parking doesn't work, the building can potentially remain in conceptual design indefinitely.

SUMMARY

2201 Westlake provided many examples where the use of post-tensioning created significant reductions in materials and shortened the construction schedule. Post-tensioning provides building designers with a sophisticated tool to create unique and efficient structural systems characterized by flexible column layouts, long cantilevers, improved serviceability, reduced depth, and limited cracking, just to name a few.

The 2201 Westlake development also has integrated green building features such as dual flush toilets; concrete countertops; 100% recycled carpets; non-VOC paints, sealants, and adhesives; energy-efficient heat pumps, central broiler, windows, and appliances; and close proximity to various public transportation options and basic services that help reduce dependence on cars.

2201 Westlake truly represents the state of the art in green building technology.

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