BUILDING WITH CONCRETE

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RECORD MAT POURS: LOTS OF CONCRETE AND 600 WORKERS

It took months to plan the two massive concrete mat foundations that support Kemper Development's $1.2 billion expansion of The Bellevue Collection.

When I think of concrete, I think of people.

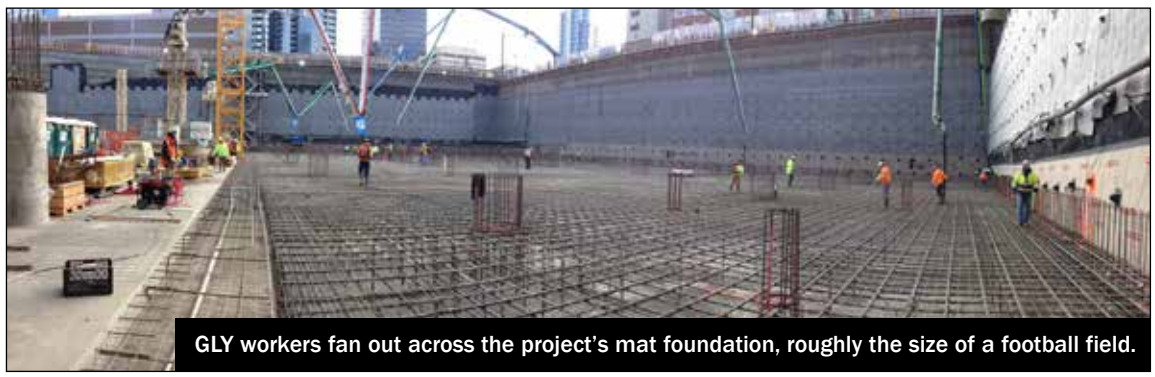
It's not as contradictory as it sounds! It took 600 of them to pull off GLY's two massive mat foundation pours in downtown Bellevue this winter: carpenters, laborers, finishers, traffic controllers, pump truck operators, concrete truck drivers, testing engineers and inspectors.

BY MELANIE COCHRUN
GLY

We also had 50 company employees volunteer to make countless hikes up and down nine flights of engineered stairs, into the deep hole, to deliver water and snacks to keep workers energized.

Over 100 visitors came to the project site at all hours of the day to witness the record-breaking work — the largest continuous mat pours in Washington to date — and more put off their shopping for a few minutes to take advantage of a viewing window down into the action.

Those are just some of the numbers for the actual pour days. It's almost impossible to count how many people participated in the planning and coordination that allowed it to occur safely, and humbling to step back and consider the extraordinary level of detail involved to ensure its quality.



GLY workers fan out across the project's mat foundation, roughly the size of a football field.

PHOTO FROM GLY

Safety is top priority

Before a single yard of concrete was poured, GLY, along with Kemper Development Co. and lead design firm Sclater Architects, began attending regular meetings this summer with the city of Bellevue to clarify regulations, establish expectations, and plan ahead for a construction activity of this magnitude.

Safety was priority No. 1, with minimizing impacts to the surrounding community of residents and businesses a close second.

Street closures were required to accommodate the seven concrete pump trucks and testing areas stationed around the site, as well as maintain the staging, delivery and exiting of more than 80 trucks delivering concrete from five different local plants.

These activities were carefully planned, down to the minute, and information communicated to the public via the city's website and a joint press release from Kemper, GLY and Sclater. Police officers, together with GLY traffic control personnel, ensured safe passage for motorists and pedestrians in traffic lanes and crosswalks adjacent to the site.

As for protecting the workers, and ensuring operations continued smoothly and as efficiently as possible throughout the two 24-hour-plus continuous concrete pours, multiple safeguards were in place. GLY's superintendents and foremen meticulously studied manpower schemes to finalize a plan that dedicated appropriate personnel.

Again, achieving a safe and accident-free execution was the first priority, and delivering the highest quality possible workmanship a close second. From the worker at each concrete pump's hopper, nozzle and vibrator, to the "gatekeeper" keeping a close watch on each entrance to the site, everyone on the team had an important role in the overall operation's success.

If things went wrong … a towing company remained on-call in the event of a concrete truck breaking down. The pumping company, Ralph's Concrete Pumping, had a back-up truck on site for each of the three different sized pump trucks being used.

GLY's in-house "McGyver" was there as well, just generally improving everyone's mood knowing any tool or piece of equipment known to man could be fixed if needed.

Complex math

Then there's planning and designing the foundation itself. It supports a $1.2 billion expansion to The Bellevue Collection. There is underground parking, a retail podium, and two separate highrises — one a 41-story hotel and residence tower and the other a 31-story office tower. The size of the foundation is determined by the size and weight of these designs, the soil bearing capacity, and the forces on the buildings during severe windstorms or an earthquake.

With that information in hand, the GLY project engineer began working with structural engineer Cary Kopczynski & Co. and concrete supplier Cadman to develop appropriate concrete mixes for city approval.

This process took months; it's not as simple as one type of concrete for the entire mat foundation. The thickness varied due to factors mentioned above. And when it comes to mass concrete, contractors must know about maximum concrete temperatures (chemical heat caused by setting it) and temperature differentials.

In order to avoid cracking damage, the maximum temperature in placed concrete cannot exceed 158 degrees Fahrenheit, and the maximum temperature difference between the center and the surface of placement cannot exceed 35 degrees. These two factors lead to improper curing as essentially, the interior portion expands relative to the surface, causing cracking.

A thermal control plan can consist of pre-installed pipes that circulate chilled water through the concrete to slow the curing process. The most famous example of this is the Hoover Dam. According to the U.S. Department of the Interior Bureau of Reclamation, there are more than 582 miles of 1-inch steel pipe embedded in the dam's 3.25 million cubic yards of concrete. (Contrary to urban legend, the dam is not still curing; cooling was complete in March 1935, nearly two years after the first concrete was placed.)

For the Lincoln Square Expansion foundation, the team instead sought to develop a variety of mix designs to limit the max internal temperature and prevent the differential between the concrete core and surface. A low heat mix limits the quantity of cement to the smallest amount possible, and uses low thermal expansion aggregates such as limestone, granite or basalt. Reinforcing steel, or rebar, is installed prior to the concrete pour to strengthen and hold the concrete in tension.

The team also used insulated concrete blankets and thermal monitoring (pre-pour installed thermometers with long cords) to prevent heat loss, maintaining a more constant temperature differential from core to surface. These blankets remained in place for over a week.

In other words, a whole lot of chemistry, physics and math — and unadulterated love of concrete — literally makes or breaks the foundation. To date, there are 38 different mixes and counting on this project, six designed specifically for the mat pours, and each painstakingly developed, lab-tested and submitted for city approval.

Even after thousands of years, builders are still inventing different ways to use concrete. We aim to make it stronger, more beautiful and quicker to place. But we need the integrated collaboration with our owner partners, design peers, community officials, and countless other hardworking, intelligent people to truly get it right. When we do, it can last forever.

Melanie Cochrun is GLY's marketing manager. She is a Certified Professional Services Marketer and lover of concrete projects, large and small.

PUBLIC WORKS: RENOVATION • SPECIAL APPLICATIONS: TECHNICAL MERIT

SNOQUALMIE FALLS POWERHOUSE RENOVATION

Crews built a new intake, penstocks and powerhouse.

PHOTO COURTESY OF WACA

Location: Snoqualmie
Owner/developer: Puget Sound Energy
Team: Barnard, general contractor; Klohn Crippen Berger, engineer; CalPortland, concrete supplier

Puget Sound Energy's Snoqualmie Falls hydropower plant is one of the oldest in the U.S., built in 1899.

The first powerhouse is encased in bedrock 260 feet beneath the surface and was the world's first completely underground power plant. The second powerhouse, a quarter-mile downstream on the north side of the falls, was built in 1910 and expanded in 1957.

GRAND AWARD

General contractor Barnard designed and built updates so that PSE could relicense the facility.

Challenges not faced in the 1800s spanned the gamut, from the existence of the now famous lodge perched above plant two's intake to the constant stream of roughly 2 million tourists per year. Barnard also dealt with calendar limitations for river work during fish migration and two 50-year floods.

Work on the 1899 underground powerhouse involved reconstruction of the intake and penstock, refurbishing four generators and replacing a fifth. Other work enlarged the plant's cavern and original 270-foot-deep shaft, and replaced the elevator.

An interpretive center was built to house one of the original generators that was replaced. The original concrete, which has supported the generators for well over 100 years, is still in place.

On the other side of the river, work on plant two involved construction of a new river intake just below the lodge, new penstocks and a new powerhouse with 12.5-megawatt turbine generator. Crews also upsized and relined the flowline tunnel that goes under the lodge.

The new river intakes on both sides required large concrete footings and precise walls to support the eight gates that weigh up to 33 tons. All were built and installed within tight tolerances.

Barnard cooled the concrete to mimic ground temperature to reduce cracking and other heat issues. Loads on ready-mix trucks were injected with liquid nitrogen to cool them. It took about 10 minutes to chill a full truck to about 50 degrees, requiring more trucks for pours.

More than 32,000 cubic yards of concrete in more than 25 mix designs were used for the project.

ON THE COVER

The Snoqualmie Falls powerhouse renovation was the grand award winner at the Washington Aggregates & Concrete Association's annual Excellence in Concrete Awards. The project also won the public works renovations and special applications technical merit categories.

PHOTO COURTESY OF WACA

DJC TEAM

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TILT-UP STRUCTURES

Painted panels and varying parapet heights help break up the scale of the buildings.

PHOTO COURTESY OF WACA

STRYKER BUSINESS CENTER (PHASE ONE)

Location: Kent
Owner/developers: Clarion Partners and IDS Real Estate Group
Team: Sierra Construction, general contractor; Craft Architects, architect; Shutler Consulting Engineers, structural engineer; Miles Sand and Gravel Co., ready-mix supplier

The first phase of the 52.5-acre Stryker Business Center includes two speculative tilt-up concrete industrial buildings of 120,600 and 318,200 square feet.

The smaller building has a 30-foot clear height and the larger one comes in at 32 feet.

Both buildings have similar features, materials and colors. Included are: painted tilt panels with varying parapet heights; offset panels at the entries; form liner and reveal patterns; steel channels attached to steel embeds; large windows; and 52-foot bay spacing for efficient rack layouts.

There also are 60-foot-deep concrete truck aprons for durability in high use areas, 15-foot-deep concrete bogey strips at trailer storage areas, cast-in-place vertical curbs in truck maneuvering areas, and concrete monument signs.

Tilt-up concrete was used for construction speed and flexibility, long life, low maintenance, durable finishes, sustainability and low cost.

WASHINGTON AGGREGATES AND CONCRETE ASSOCIATION
2015 EXCELLENCE IN CONCRETE CONSTRUCTION AWARD WINNERS

GRAND AWARD
Public works: Renovations
Special applications: Technical merit
Snoqualmie Falls powerhouse renovation
Snoqualmie

Public works: Bridges
Montlake Triangle pedestrian bridge
Seattle

Public works: Infrastructure
U-240 Capitol Hill Station
Seattle

Tilt-up structures
Stryker (phase one)
Kent

Cast-in-place structures (tie)
Philadelphia Macaroni rail receiving building
Spokane

Viktoria
Seattle

Architectural/decorative concrete
Block 44 Amazon (phase six)
Seattle

Pervious concrete
Cascade Middle School
Sedro-Woolley

Concrete paving
Marysville Ford
Marysville

Special applications: Artistic merit
Banyan Wilds Exhibit
Woodland Park Zoo

Sustainable merit
Stone34
Seattle

PUBLIC WORKS: BRIDGES

MONTLAKE TRIANGLE PEDESTRIAN BRIDGE

Location: Seattle
Owner/developer: Sound Transit
Team: Hoffman Construction Co., general contractor; Hoffman Structures, concrete contractor; LMN Architects, architect; Aecom, structural engineer; Cadman, read-mix supplier; Gerdau, rebar supplier and installer; Peri Formwork Systems, specialty formwork

The Montlake Triangle pedestrian bridge is a highly curved, 427-foot-long bridge spanning Montlake Boulevard between the Sound Transit light rail station and the University of Washington campus.

The bridge was designed and built as part of the University Link project to extend light rail from downtown Seattle to the UW. Its layout consists of an outside curve with a 152-foot radius and an inside curve with a 94-foot radius.

Its span hinges divide the bridge into three segments. The inside and outside curves are cast-in-place, post-tensioned concrete single-cell box girders that transition to a three-cell box where the curves converge.

Post-tensioning was chosen to allow a shallow section of the bridge to meet vertical clearance requirements. It also produced a high-level architectural finish without the typical cracking associated with reinforced concrete bridges.

Crews had to form and construct the bridge over a main arterial road without interrupting traffic.

Design and construction of the project pushed the limits for use of post-tensioning in highly curved bridges, demonstrating that durable, low-maintenance, high-aesthetic post-tensioned bridges are a viable option for transportation projects.

The bridge's outside curve has a 152-foot radius and its inside curve has a 94-foot radius.

PHOTO COURTESY OF WACA

PUBLIC WORKS: INFRASTRUCTURE

U-240 CAPITOL HILL STATION

Location: Seattle
Owner/developer: Sound Transit
Team: Turner Construction, general and concrete contractor; Northlink Transit Partners, architect; Jacobs, structural engineer; CalPortland, ready-mix supplier

The Sound Transit light rail line between Capitol Hill and Husky Stadium is expected to open in fall 2016.

Capitol Hill Station houses most of the support machinery for the power, communication and ventilation of the tunnels in both directions. It also will be a passenger stop, where Sound Transit estimates 14,000 riders will board daily by 2030.

Construction of the station involved 3.5-foot-thick exterior walls, reinforced concrete strut members spanning the width of the station that are just over 3 feet and 5.5 feet in diameter, and suspended slabs up to 4 feet thick.

The below-ground "station box" or platform area is where passengers will catch their trains. Walls in this area are exposed concrete, and the entrances to the station include reveals of exposed concrete to contrast with the tile and metal panel finishes.

The challenge for the station box was the open area without intermediate decks, about 51 feet from top to bottom. Crews used an out-of-the-box concrete forming system with collapsible steel trusses that spanned the 45-foot width of the station box.

The truss system sat on a set of rails with rollers on it, and once the concrete was poured and started curing, workers disassembled the system and slid it to the next section to prepare for the next pour — up to 40 linear feet at a time.

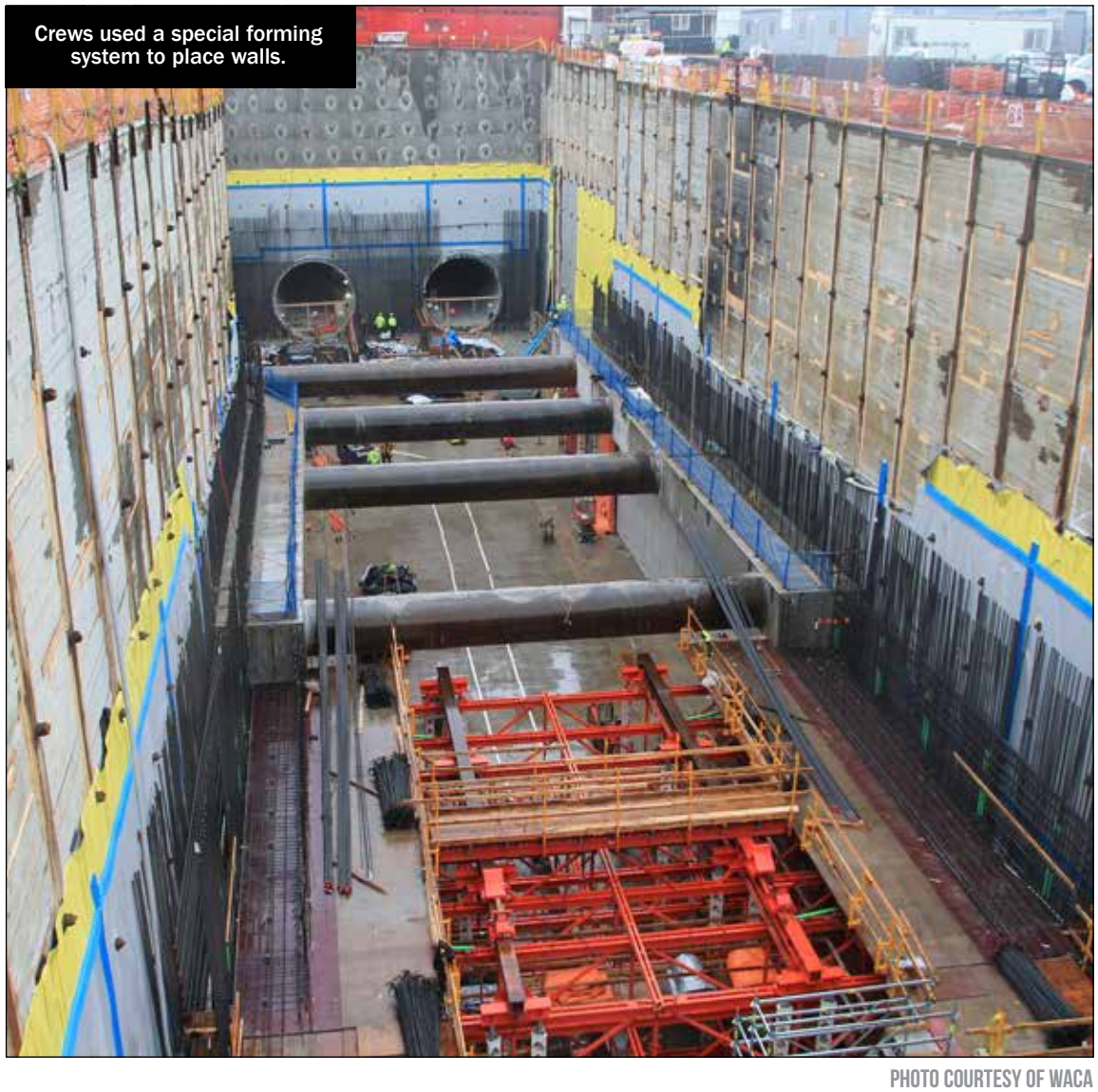
The result was a nice finish for exposed concrete walls and fewer construction joints.

With such large sections, and a stringent temperature requirement, mass concrete mitigation was important. Using methods such as water circulation post-cooling and liquid nitrogen pre-cooling, crews kept concrete temperatures below 145 degrees and changes in temperatures to less than 35 degrees.

Instead of typical foam build-up, designers opted for cellular concrete backfill for voids in the structure. This lightweight specialty concrete was batched and placed on site, and made up nearly 1,400 cubic yards of the total.

The overall station used nearly 29,000 cubic yards of concrete and more than 7.3 million pounds of rebar.

The team had a DBE/SBE/WBE inclusion rate of nearly 25 percent on the concrete work, as well as union apprentices contributing nearly 19 percent of the total labor hours. The job also had female and minority inclusion of 30 percent of the total labor hours.



Crews used a special forming system to place walls.

PHOTO COURTESY OF WACA

ARCHITECTURAL/DECORATIVE CONCRETE

BLOCK 44 AMAZON (PHASE SIX)

Location: Seattle
Owner/developer: Vulcan Real Estate
Team: GLY Construction, general contractor; ZGF Architects, architect; Coughlin Porter Lundeen, structural engineer; Cadman, ready-mix supplier

Block 44 consists of five- and six-story buildings with 380,700 square feet of office space and 15,000 square feet of retail over subterranean parking at the corner of Westlake and Mercer. The buildings are linked by a glass canopy over a concrete pedestrian breezeway running between them.

A rooftop terrace for tenants has pathways that interweave with landscaping.

For the public, open space surrounding the buildings can be found at ground level. The breezeway, or crossblock, is bookended by water features, outdoor seating and landscaping. The glass canopy six stories above grade provides weather protection and is a public art installation that transforms the courtyard below to a wooded floor as light shines through the glass. When natural light is low, 100 twinkling LED "fireflies" are choreographed to mimic a forest at dusk.

With an average 10-foot elevation change from one end of the crossblock to the other, nothing was parallel or square. The contractor precisely modeled the complicated geometry, including multiple elevation points, to ensure smooth concrete paving throughout.

Walls for the water features varied from 6 to 8 feet tall, with a finished walking slab on top. Each piece is essentially a waterproof concrete bathtub invisible below grade.

Finally, the contractor removed and replaced aggregate by hand before the curing process to achieve the right degree of exposure.

A concrete pedestrian breezeway runs between the two buildings at Block 44.

PHOTO COURTESY OF ZGF ARCHITECTS

PERVIOUS CONCRETE

Crews poured pervious concrete over nearly 4 acres at Cascade Middle School.

PHOTO COURTESY OF WACA

CASCADE MIDDLE SCHOOL

Location: Sedro-Woolley
Owner/developer: Sedro-Woolley School District
Team: Colacurcio Brothers Construction, general contractor; LangCo NW, concrete contractor; Concrete Nor'west, ready-mix supplier

Cascade Middle School has been operating for nearly 60 years in Sedro-Woolley and needed upgrades to its structures and grounds.

As part of a $20 million renovation, the school district identified infiltration as the best way to control stormwater runoff. After evaluating several methods, officials decided on permeable pavement because of the large amount of infiltration area beneath the pavement.

Pervious concrete was selected for its durability and structural integrity, allowing it to handle heavy buses. Officials also liked pervious concrete for its light, reflective surface that helps reduce the heat-island effect.

Another benefit of an infiltration system is no need to build conventional stormwater system components such as catch basins, pipes and vaults.

About 3,500 cubic yards of pervious concrete was used on nearly 4 acres of the site. The pavement is 4 inches thick for sidewalks, 6 inches for parking areas and 8 inches for the bus lane. It was strengthened with admixtures and fiber mesh.

The project earned credits under the Washington Sustainable Schools Protocol, the green building standard for schools in Washington. Teachers are using the pavement to educate students about pollutant removal, infiltration rates and stormwater management.

CAST-IN-PLACE CONCRETE TIE

PHILADELPHIA MACARONI RAIL RECEIVING BUILDING

Location: Spokane
Owner/developer: Philadelphia Macaroni Co.
Team: Divcon, general and concrete contractor; J.R. Bonnett Engineering, structural engineer; Oldcastle Materials, ready-mix supplier

Using cast-in-place concrete for the tunnel eliminated potential problems with precast panels.

PHOTO COURTESY OF WACA

The Philadelphia Macaroni rail receiving building is a 300-foot-long and 27-foot-tall cast-in-place above-ground tunnel that can accommodate up to five rail cars for unloading. It is the first step that the owner uses to make pasta.

The covered spur is used to unload rail cars filled with semolina flour in a semi-controlled environment. The cargo is transported about 350 feet away into silos through a complex network of pipes and compressed air. Due to the flour dust and moisture generated from daily operations, the owner required electrical, communications and control systems to be contained within the concrete walls in lieu of surface mounting.

The project was originally designed with precast concrete wall and roof panels. While the concept was possible, constructability was problematic due to several issues.

The first concern was connecting as many as 15 rows of conduit that were to be set into the 60 precast panels. That would have required the contractor to align the many cast-in conduit components while erecting the precast panels. With 56 panel joints containing these connections, the likelihood of multiple conduit connections being misaligned and unusable was inevitable.

The second concern was the lack of access on the site. The west side of the tunnel is on railroad property with no access and the east side has about 25 feet of space, severely limiting the size of a crane and making erection of precast panels extremely inefficient and expensive.

Divcon proposed using cast-in-place concrete in lieu of precast to eliminate complexities of the original design. This allowed all conduit, electrical panels and junction boxes to be cast directly in the wall and soffit concrete.

Using cast-in-place concrete also reduced the size of the crane needed to the point that access was no longer an issue.

The result was a superior concrete structure with lower construction costs, as well as lower operating and maintenance costs.

Viktoria was built with a two-way post-tensioned slab system that eliminated all internal columns.

PHOTO COURTESY OF WACA

VIKTORIA

Location: Seattle
Owner/developers: Goodman Real Estate and Mack Urban
Team: Turner Construction, general and concrete contractor; Weber Thompson, architect; Cary Kopczynski & Co., structural engineer; CalPortland, ready-mix supplier

Located in downtown Seattle near Pike Place Market, Viktoria is a 25-story tower with 249 upscale apartments.

With panoramic views of the city and water, the entire 25th floor is devoted to socially focused amenities. A butterfly roof cantilevers more than 20 feet from the enclosed portion of the sky lounge, and features an evergreen tree that pierces the roof through an oculus.

The building's structural system consists of cast-in-place concrete with post-tensioned floor slabs and a shear wall core for seismic and wind resistance. Structural member sizes were minimized through the use of high-strength concrete and reinforcing bar, which also reduced total concrete volume and steel tonnage.

From the inception of the project, the owner and architect desired a contemporary urban environment with spacious open layouts to maximize usable square footage. The structural engineer responded with an innovative solution that eliminated all internal columns.

That solution was a two-way post-tensioned slab system. By thickening the slab to 16 inches for a distance of 6 feet around the core, creating a large "drophead," spans of nearly 40 feet from the core to the exterior glass were made. This eliminated all internal columns in all units.

With no interior columns, the majority of the building's dead load was supported by the core. This significantly reduced the net uplift forces at the core from wind and seismic loads. As a result, core wall reinforcing quantities dropped by over 12 percent. This rebar savings more than compensated for the drophead costs, creating a net savings to the project.

The drophead eliminated the need for transfer beams, which would have been required to relocate interior columns as they pass through the lower retail, lobby and parking levels.

Viktoria's obstruction-free layout also streamlined installation of non-structural interior walls, eliminating the need to build these walls around restrictive columns.

The combination of post-tensioning and the drophead around the core created a more uniform and consistent deflection distribution. Thus, the slabs are less susceptible to serviceability problems.

The use of post-tensioned concrete allowed for 8.5-inch slabs, despite the ultra-long spans. This minimized structural mass and seismic forces, benefiting the columns, core walls and foundations.

State-of-the-art seismic analysis tools were used to predict building drift and post-tensioned slab diaphragm deflection. The structural design minimized lateral drift during an earthquake, eliminating the possibility of contact with surrounding buildings.

CONCRETE PAVING

MARYSVILLE FORD

Location: Marysville
Owner/developer: Marysville Ford
Team: Perlo Construction, general contractor; Mildren Design Group, architect; T.M. Rippey Consulting Engineers, structural engineer; Smokey Point Concrete, concrete contractor and ready-mix supplier

Concrete was used throughout the new Marysville Ford dealership for tilt-up walls, polished floors in service bays, the stained and polished entryway in the customer service area, the detail shop with inside car wash and exterior drive-thru car wash, upper mezzanine deck office and expansive parking lot.

For the 5-acre parking lot, the owner wanted performance and durability, low lifetime maintenance, a clean and bright appearance, and versatility.

The lot was originally designed to be paved in asphalt, but the owner chose concrete after discussions with Smokey Point Concrete.

Concrete was picked for its resistance to temperatures, its increasing strength as it ages, and its lack of annual sealing, patching or periodic resurfacing. It also is cooler in the summer for customers and workers.

Smokey Point Concrete used the National Ready Mixed Concrete Association's Design Assistance Program to help it build the parking lot. This program addresses key considerations such as traffic conditions, vehicle weight, pavement strength and thickness, subgrades and joint spacing.

Concrete was picked over asphalt for the 5-acre parking lot.

PHOTO FROM WACA

SUSTAINABLE MERIT

STONE34

Location: Seattle
Owner/developer: Skanska
Team: Skanska, general and concrete contractor; LMN Architects, architect; DCI Engineers, structural engineer; CalPortland, ready-mix supplier

Concrete was vital to the success of this 225,000-square-foot Fremont office building that uses cutting-edge sustainable building technologies and is part of Seattle's Deep Green pilot program.

Stone34, which opened last summer, is designed to capture at least half of on-site stormwater and use 75 percent less energy and water than comparable office buildings. It achieved LEED platinum certification and is designed to meet at least 60 percent of the Living Building Challenge guidelines.

Stone34 has a 76,000-gallon container on the roof that collects rainwater to reuse throughout the building, while more than 17,000 cubic feet of underground cisterns and detention vaults store excess stormwater. A post-tensioned concrete framing system supports this massive water collection system, as well as an extensive green roof and accessible deck.

The building's post-tensioned concrete slab system maximizes the reach of sunlight throughout the interior. Wide and shallow concrete beams run from the center of the building to the exterior column line. These beams cut down on the need for vertical columns that would block views or interrupt sunlight. With no perimeter beams, the windows were extended to the undersides of the slabs, allowing greater light infiltration.

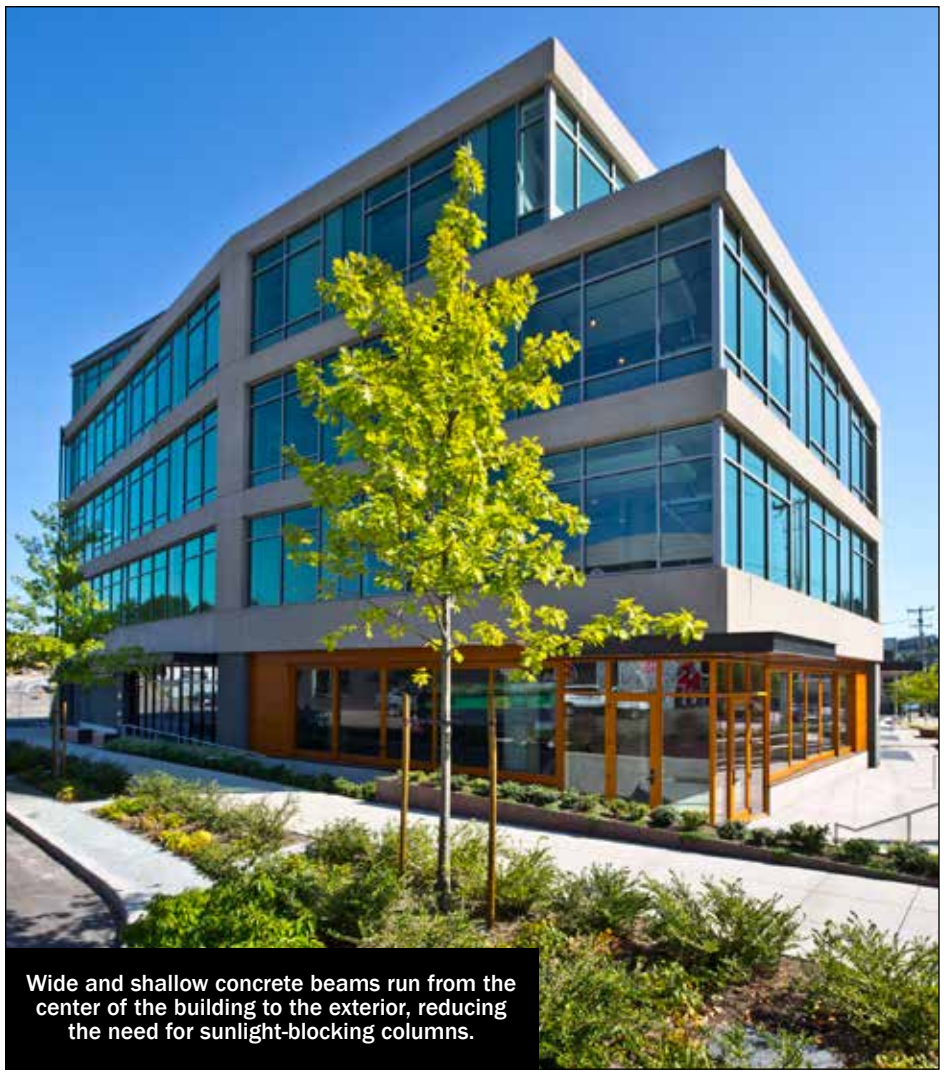
Office ceilings were left exposed, which enhances natural daylight and reduced the amount of construction materials.

The concrete framing system also provides thermal mass. Combined with hydronic plates and chilled beams, the interior temperature is efficiently regulated with limited need for conventional heating or cooling.

The structural engineer worked with the developer and general contractor early on, and used Revit and building information modeling to save time and minimize wasted materials and resources.

The building's shear wall layout consists of simple straight walls, which eliminate the need for a central core, making for cheaper formwork and faster set times. This design also eliminated most of the pilasters in the basement, which allowed walls to be constructed of shotcrete — a cheaper and less resource-intensive solution than traditional concrete.

Precast planks were used for the detention vault lids and 7-inch-thick slabs were used to reduce the building's seismic mass.



Wide and shallow concrete beams run from the center of the building to the exterior, reducing the need for sunlight-blocking columns.

PHOTO COURTESY OF WACA

SPECIAL APPLICATIONS: ARTISTIC MERIT

BANYAN WILDS EXHIBIT

Location: Seattle
Owner/developer: Woodland Park Zoo
Team: Forma Construction, general contractor; Turnstone Construction, concrete contractor; Studio Hanson Roberts, architect; Howe Engineering, structural engineer; Salmon Bay Sand & Gravel, ready-mix supplier

Banyan Wilds is the Woodland Park Zoo's most ambitious new exhibit in nearly two decades.

The 2-acre exhibit immerses guests in the tropical forests of Asia, and tells the story of Asia's magnificent animals and their habitats. The first phase opened in 2013, displaying small clawed otters, and the second phase, homes for Malaysian tigers and sloth bears, was recently completed.

Shotcrete was placed and manipulated to represent the textures, forms and colors of an Asian rain forest, including termite mounds, earthen embankments and root balls.

Steel armatures provided the shape and forms of rocks, trees and vines. Crews shotcreted the armatures with custom mixes that allowed the artistic team to develop fine details using tools as small as dental picks and fine paintbrushes.

In some areas, electrical cables were placed between layers of concrete to heat the dens and prominent rock structures that the animals rest on. Concrete both protects the cables and provides the mass that they heat for the animals' comfort.

Concrete also is a durable surface that can withstand the high impacts of tigers and bears.

Pervious pavement colored in earthen tones was used in areas not planted or covered in textured shotcrete, including a path designed as a forest road that visitors navigate in the exhibit. Crews manually compacted the material and worked carefully alongside surrounding trees and plantings.

In some areas, zoo visitors walk on concrete colored in earthen tones and embossed with animal tracks.

Structural concrete was used as a durable and cleanable surface in the back-of-house areas.

Shotcrete was used to create rocks, waterfalls, pools, trees and vines.

PHOTO COURTESY OF WACA