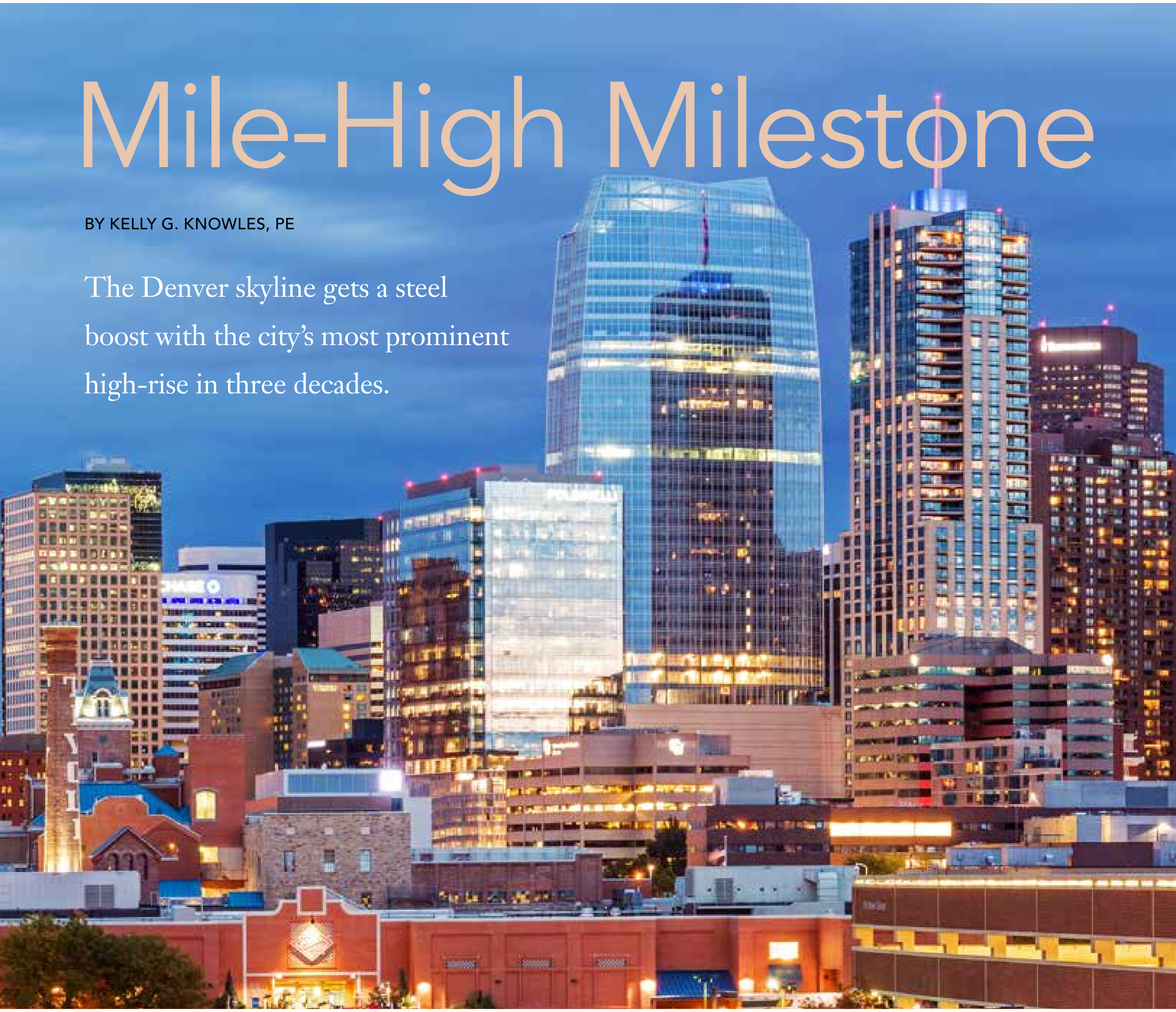
Mile-High Milestone

BY KELLY G. KNOWLES, PE

The Denver skyline gets a steel boost with the city's most prominent high-rise in three decades.



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THE DOWNTOWN DENVER SKYLINE has remained largely unchanged ever since a handful of high-rise office buildings were completed during the petroleum boom of the 1980s.

No longer.

With the opening of 1144 Fifteenth Street this past spring, the skyline has gained a new focal point: a steel-framed architectural gem with brilliant angular planes culminating in a faceted crown. A snow-capped peak of sorts meant to evoke the Rocky Mountains to the west.

At 603 ft, 1144 Fifteenth stands as Denver's fourth-tallest building, and its geometry bucks the typical practice of simple prismatic-shaped high-rise construction. The columns on the east and west faces of the building begin to lean inward at the 26th floor, while the north and south face columns begin their lean at the 33rd floor at a gentler angle. Finally, at the 40th floor, the geometry changes once again with one last angular shift upward to the building's crown. Floor framing at the building's corners cantilevers

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Denver Infill

16 ft, allowing for column-free space. The complicated geometry of the building form created difficult beam-to-column connection challenges. Each unique connection was modelled to ensure design and construction challenges could be overcome.

The building's 980,000 sq. ft of space comprises a 27-story office tower above a 13-story parking podium and an additional two stories of below-grade parking. The 5,000-ton primary frame for the office tower consists of steel beams and columns on composite deck, while the garage is concrete-framed. ASTM A913 65-ksi steel was used for the tower columns. As the layout of the tower columns and parking garage columns did not match in a number of locations, two-story concrete transfer columns were employed.

A significant challenge for the structural team was addressing the issue of differential shortening between the cantilevered core and the steel columns, a complexity made even more difficult by the concrete columns below the office tower. The core experiences vertical shortening through the course of construction due to concrete shrinkage, elastic shortening and longer-term creep shortening—with values exceeding more than 7 in. of total shortening—while the steel columns undergo elastic vertical shortening due to application of vertical load. The concrete podium columns experience the same effects as the concrete core but see a much higher degree of elastic shorting due to a substantial collection of axial load. Ultimately, coupled with the contractor's schedule, a plan was devised to over-lengthen each element—the concrete columns, concrete core and steel columns—to varying degrees to ensure a level floor. The in-house detailing team of steel fabricator Puma Steel was tasked with producing a building information model (BIM) with accurate floor

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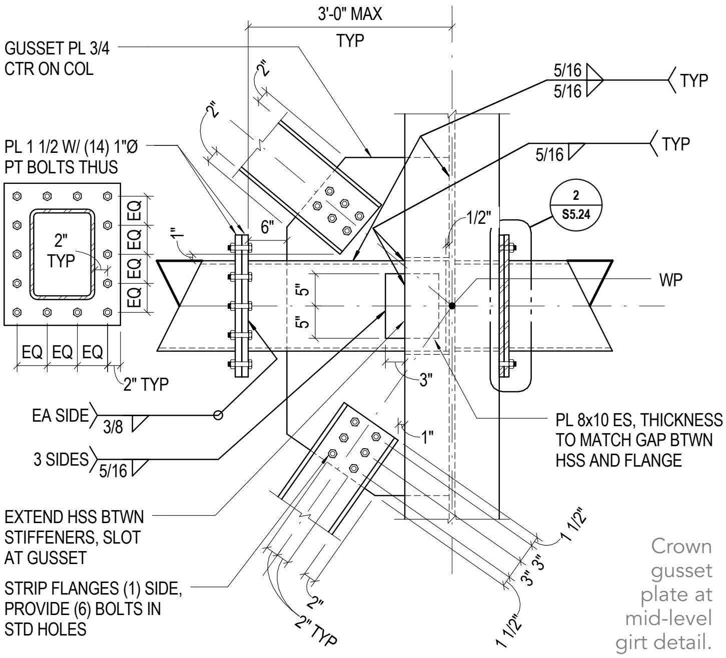
elevations for use in coordination with other disciplines, while still finding a way to fabricate the columns with the required overlength. Building surveys were conducted during construction to monitor overall shortening and building behavior, and the building shortening values were shared with the curtain wall manufacturer to aid in the design and detailing of the horizontal stack joint.

Early involvement of the steel fabricator allowed Puma Steel to engage Martin/Martin's construction engineering services team to help reduce cost and schedule through customized connections. The focus of the collaborative effort was to play to the strengths of Puma Steel's highly automated shop and reduce field labor for the steel erector. The use of innovative bolted extended shear connections took advantage of Puma Steel's automation, eliminated nearly 1,000 beam copes and provided the erector with greater clearance to place filler beams between the concrete core and perimeter steel girders. By working with the design team, actual moments were considered at the cantilever connections through the columns at the four corners of the structure. The results were reductions in stiffener requirements as compared to industry standard details that develop the strength of the beams, and the conversion of nearly 1,600 complete-joint penetration welds to double-sided fillet welds or built-up partial joint penetration welds.

A wind tunnel study was commissioned in an effort to achieve economies in the design of the curtain wall and to better understand the wind effects on the irregularly shaped building. The resulting wind analysis included a reduction in the main wind force-resisting system loads when compared to the loads generated through building code analysis, which in turn were incorporated into the analysis and design of the lateral load-resisting system. Initially, one-story-tall steel outriggers were incorporated into the design to compensate for a slender core and as a mechanism to control building drift. The favorable results from the wind tunnel study allowed for the removal of the outriggers, a considerable cost



Crown gusset plate at mid-level girt detail.

and schedule savings. Furthermore, the analysis included the results of wind-induced accelerations. These showed acceleration levels below those than what would be considered acceptable for a residential occupancy, which, for an office building situated on the downslope side of the Rocky Mountains, is a rather impressive achievement. Local areas of high wind pressure were also identified, including considerable wind uplift effects necessitating positive anchorage of terrace pavers to the supporting concrete substrate.

The gradual lean of the tower culminates at a bifurcated crown, the capstone feature of the building. Leaning column base thrusts are resisted with wide-flange drag beams delivering axial forces to the concrete core. The crown, with its faceted planes expressing the top in a unique way, included other design challenges such as a 35 ft tall parapet. At the parapet, the out-of-plane lateral loads are resisted by wide-flange steel columns spanning vertically to a steel truss situated at the top. In-plane lateral loads are resisted by multi-tiered steel braced frames. The geometry of the tall parapet was closely coordinated with clearances required for maintenance equipment that navigates the roof via rail and is stowed in the northeast corner. The horizontal truss framing connections were developed through collaboration with Puma Steel in an effort to accelerate fabrication and erection. Part of this strategy involved welding the gusset plates in the shop and employing field bolting during erection.

The result is a prominent new high-rise and one of the most coveted commercial addresses in Denver—one that raises the profile of the Mile High City even higher. ■

Owner/Developer
Hines

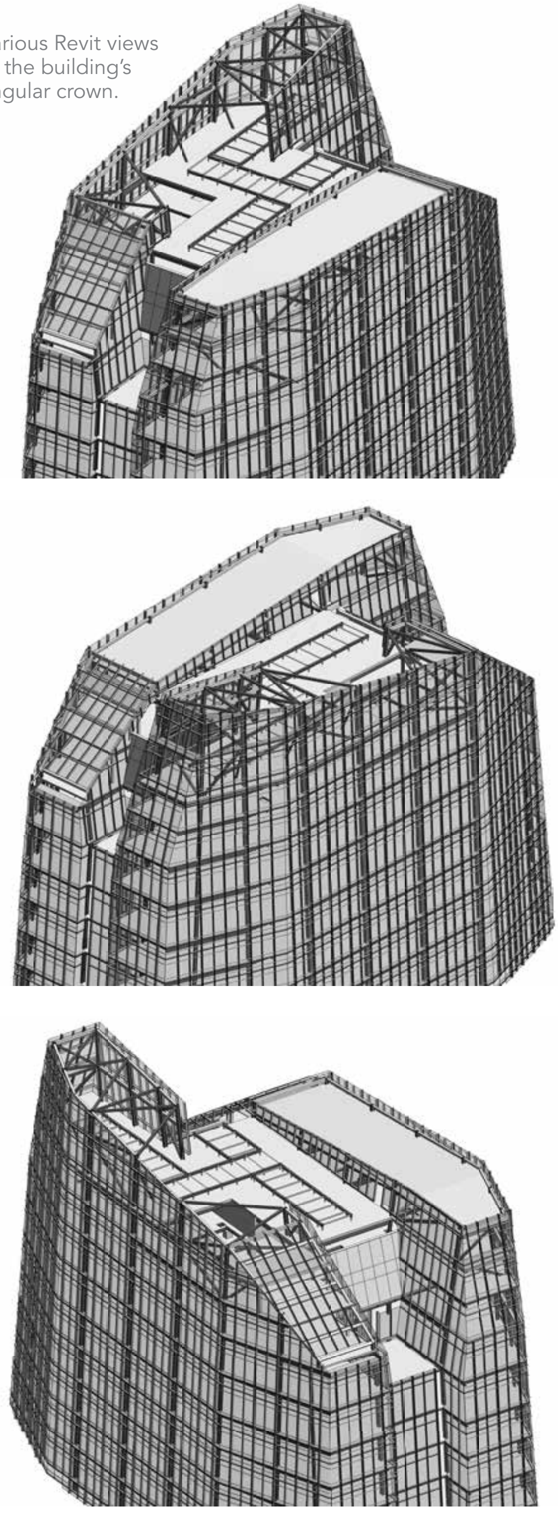
General Contractor
Hensel Phelps, Denver

Architects
Pickard Chilton, New Haven, Conn.
Kendall/Heaton Associates, Inc., Houston

Structural Engineer
Martin/Martin, Inc., Lakewood, Colo.

Steel Fabricator and Detailer
Puma Steel, Cheyenne, Wyo. AISC CERTIFIED FABRICATOR

Various Revit views of the building's angular crown.



Framing for the crown.