Tower of STRENGTH

BY AMBER SHOALS, PE, MARK TAMARO, PE, PETER DRAKE, PE, AND KEVIN MACLEOD, SE, PE

A new addition to the Virginia Military Institute campus provides state-of the-art physical readiness training for cadets year-round.

THE VIRGINIA MILITARY INSTITUTE'S MOTTO, "In Pace Decus, In Bello Praesidium," translates to "In Peace a Glorious Asset, In War a Tower of Strength."

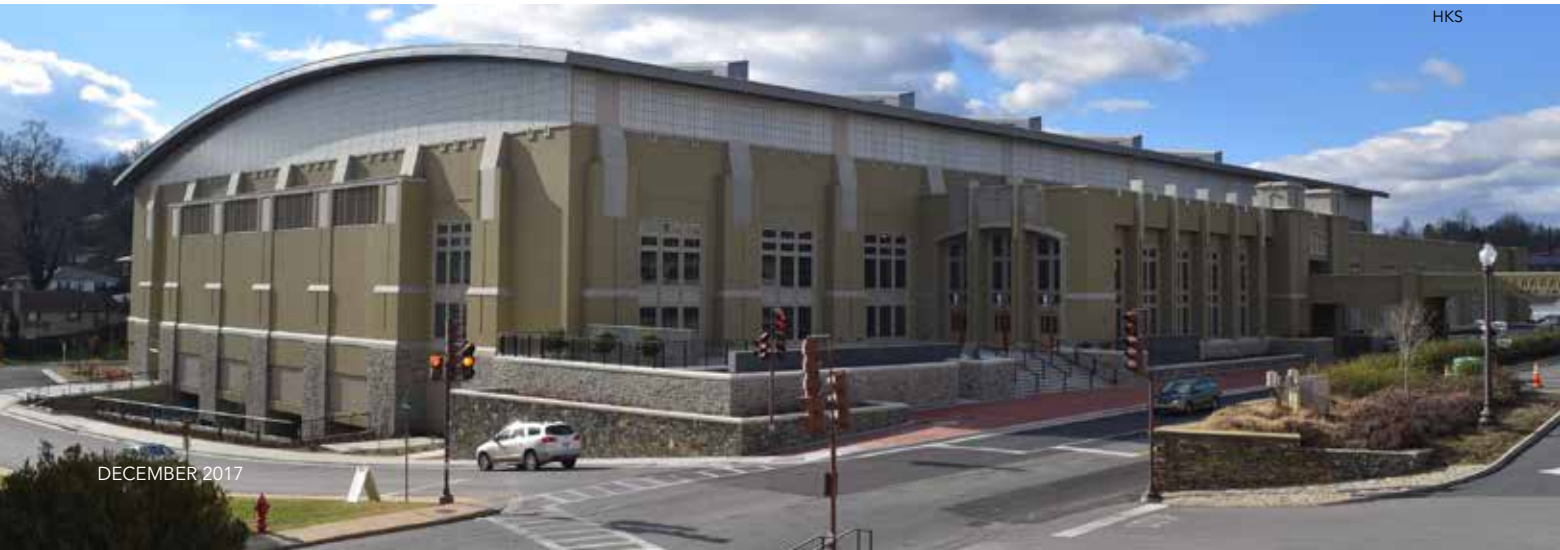
The school's new Corps Physical Training Facility (CPTF) is geared toward turning its students into towers of strength. The 205,000-sq.-ft. steel-framed, arched-roof building presented the design team with multiple challenges. These, however, must pale in comparison to the intense training the cadets undergo inside this new facility, which is chock-full of amenities made to elevate their physical fitness year-round.

Founded in 1839, the Virginia Military Institute is a four-year undergraduate college in Lexington, Va., that provides cadets with the skills necessary to succeed in military careers. The nation's oldest state-supported military college, its curriculum combines a rigorous education with a physically demanding environment. The new CPTF, which opened in late 2016, is the newest addition to VMI's historic campus.

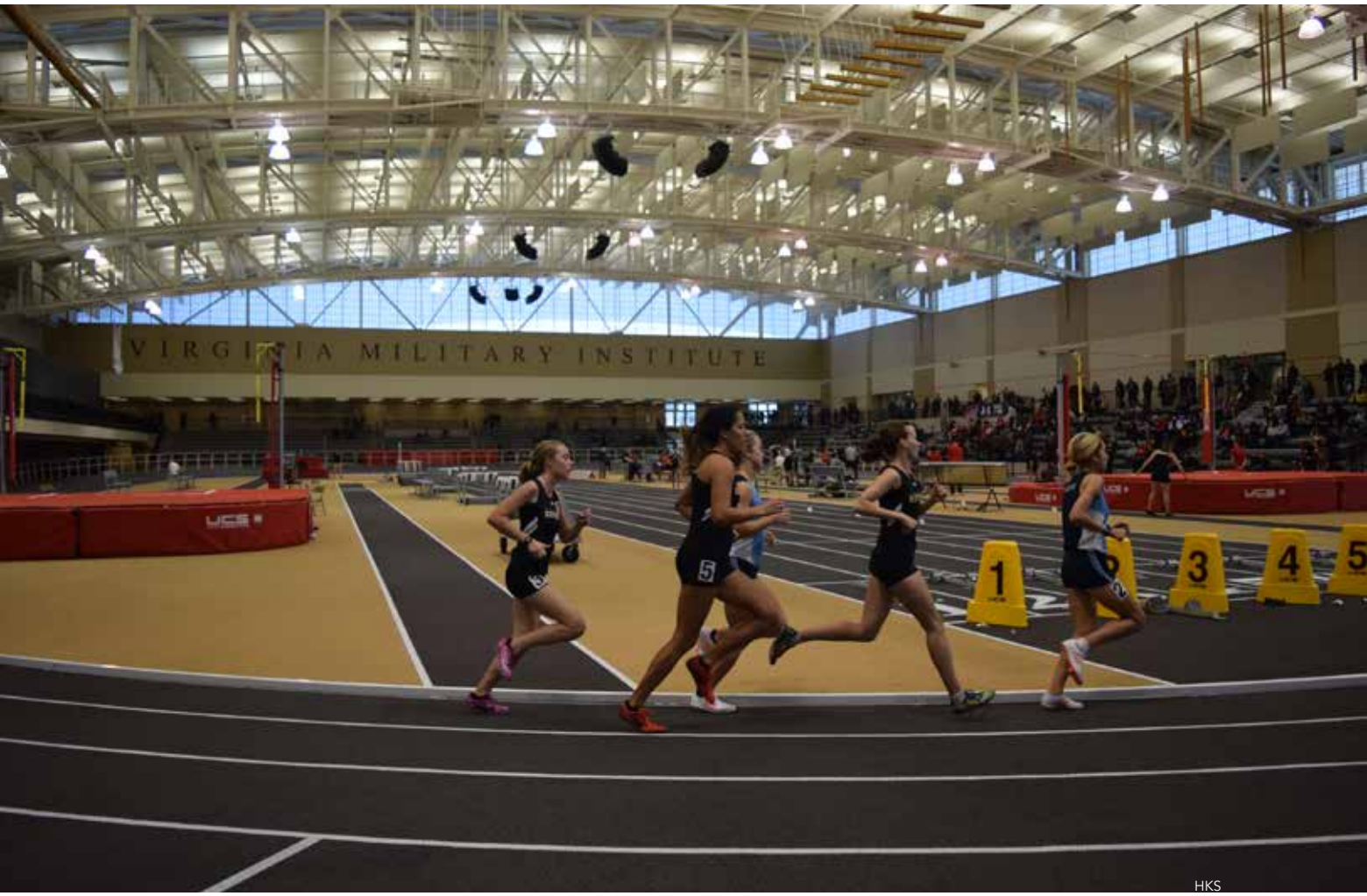
Designed by HKS Architects with Thornton Tomasetti providing structural engineering services, the new facility embraces the gothic revival style of Alexander Jackson Davis's original 19th century campus design. Despite its medieval exterior, inside CPTF is all state-of-the-art. The building features a 200-m track with hydraulic banking, an elevated three-lane track, weight and cardio training rooms, locker rooms built to NCAA standards, a rock-climbing wall, an obstacle course, physical and combat readiness training and seating for 1,800 spectators. Among its unique features is a high-ropes course above the main track, made possible by structural steel box trusses that allow for a massive column-free space. Other forward-thinking design elements include several sustainability strategies, such as a vegetated roof, a state-of-the-art downdraft air circulation system and underground cisterns that collect rainwater for use at the facility, all of which contributed to the anticipated LEED Gold certification.

The Corps Physical Training Facility is VMI's newest building.

Photos courtesy of Thornton Tomasetti unless otherwise noted.



HKS



▲ One of the building's highlights is its 200-m track.

Superstructure

The facility's primary superstructure consists of two elevated levels of composite steel framing with slab on metal deck. This two-story structure wraps the northern and western sides of the main training floor and houses the locker rooms, classrooms and office space. The typical bay spacing here is 30 ft by 40 ft and it is supported by W18 beams, W24 girders and W14 columns. The office structure roof also supports the green roof system.

An elevated three-lane, 350-m-long track cantilevers above the main floor off the perimeter wall columns at the south and east sides. Fixed bleacher seating on the north and west sides is supported by sloping steel raker beams, with the seating treads and risers being constructed of composite metal deck and concrete slabs.

The column-free space over the main floor is made possible by structural box trusses spanning 220 ft in the north-south direction. These architecturally exposed trusses are designed to

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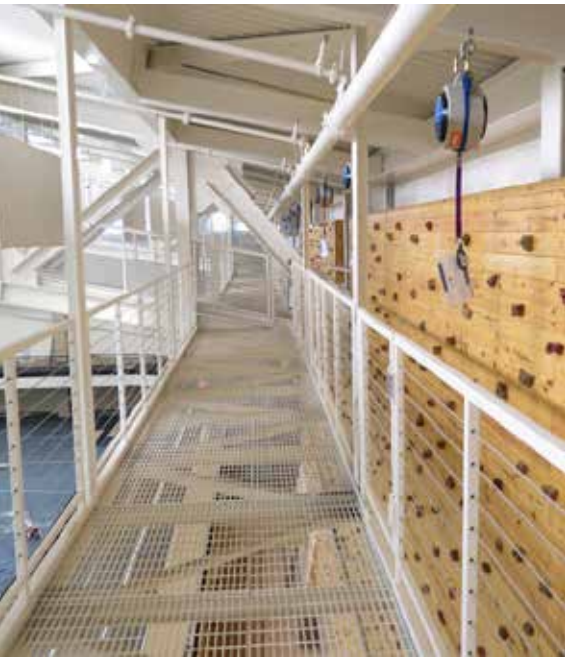
▲ The challenge course, integrated with the roof trusses.

◀ Roof joists, prior to erection.

▶ Building the roof.

▼ Catwalk and climbing wall.



match the curvature of the vaulted roof, which at the apex is 60 ft above the main floor. The box trusses are 6 ft wide by 12 ft deep, spaced at 60 ft on center, and open-web steel joists span between them in the east-west direction.

The approximately 405-ft-long building is laterally supported by steel braced frames along its perimeter. The roof framing has a discrete system of horizontal bracing in plane to form a diaphragm, consisting of double angles, and distribute lateral loads to the perimeter braced frames. Steel wide-flange columns surrounding the high space support a grid of rotated wide-flange girts that provide lateral support for the building façade's precast panels.

Climbing High

Thornton Tomasetti's structural engineers worked closely with HKS early in the project to develop an integrated truss design that would support the curved roof structure and allow access to the unique high ropes course. One specific design consideration for curved trusses that is different from traditional flat trusses is how to accommodate the horizontal effects resulting from vertical loads on the arched shape. Based on the building geometry, the north ends of these trusses had to be integral with the structural diaphragms of the offices, and the south ends of the trusses needed to be supported directly on the exterior wall. There would be little room for movement on the north end.

In response to the building form, Thornton Tomasetti chose to allow the trusses to displace horizontally at the south support. As the box trusses deflect vertically, they generate a horizontal displacement of roughly 3 in. This displacement was accommodated by the ability of the 40-ft-tall southern perimeter truss columns to flex, allowing the structure to deflect outward under gravity loads. The length of the column provided inherent flexibility, and the column base and truss chord connections were detailed to accommodate the rotation. The resulting frame displacement was coordinated with the design team, resulting in the precast façade panel joints being located and detailed around the expected movement.

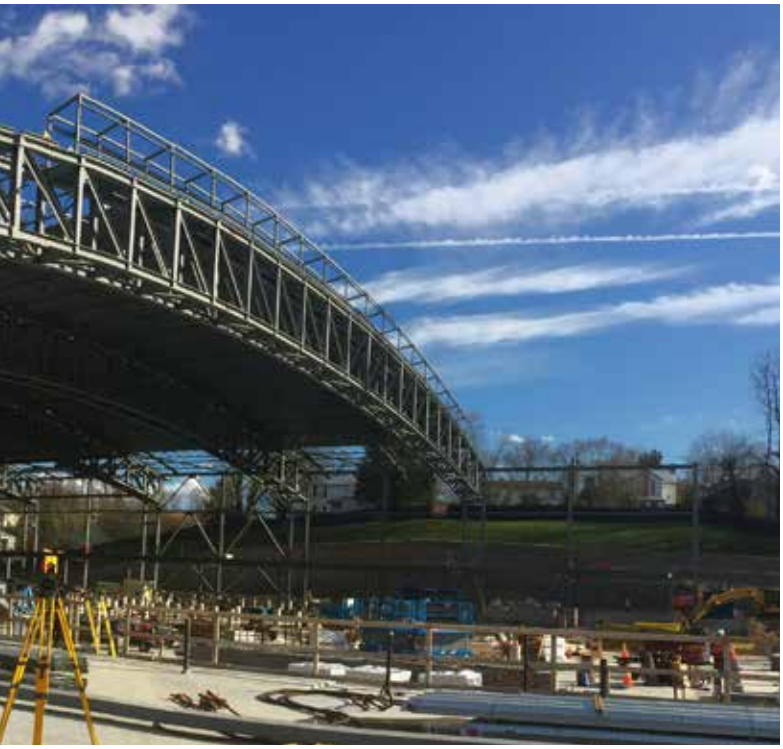
Challenge Course

The challenge course consists of both team and individual events and is intended to provide cadets experience in effective leadership, followership and problem solving. It requires cadets to move safely and seamlessly through the structural elements of the roof framing to access challenge course obstacles suspended nearly 60 ft above the main training room floor.

Integrating the challenge course into the design of the box trusses and roof framing required coordination from all disciplines. The truss design and layouts were coordinated with the desired aesthetics and the ropes course program, including member sizes, orientation and the overall curvature of the truss chords. This coordination was especially important, as the truss structure and connections would be exposed as part of the design.

The three easternmost box trusses provide catwalk access to the high ropes course suspended from the main roof. In these bays, which would typically incorporate open-web joist framing at the roof, wide-flange beams were used as they permitted greater flexibility in the course layout by allowing potential concentrated loads to be located anywhere along the length of the beam.

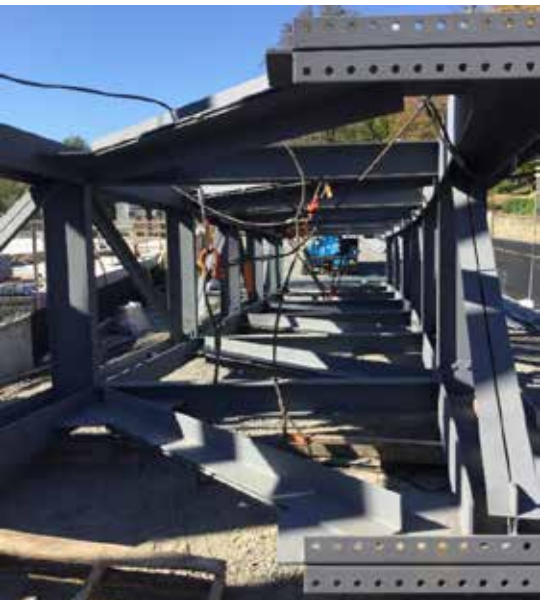
At the typical box trusses, diagonal members were provided through the cross section of the box to link two planar trusses together to act as one composite box shape. However, at the trusses over the ropes course, the center of the box needed to be kept open for catwalk access to the ropes course platforms. To maintain the box effect without the diagonals, the truss vertical members were moment connected to the horizontal cross members between the trusses, creating a portal frame at each truss vertical. The moment frames are less efficient than the diagonal braces, so five moment frame panels were required at each truss compared to only three diagonal braces at the typical truss. Although this increased the



▲ The box trusses are spaced at 60 ft on center, and open-web steel joists span between them in the east-west direction.

▼ Challenge course obstacles, 60 ft above the floor.

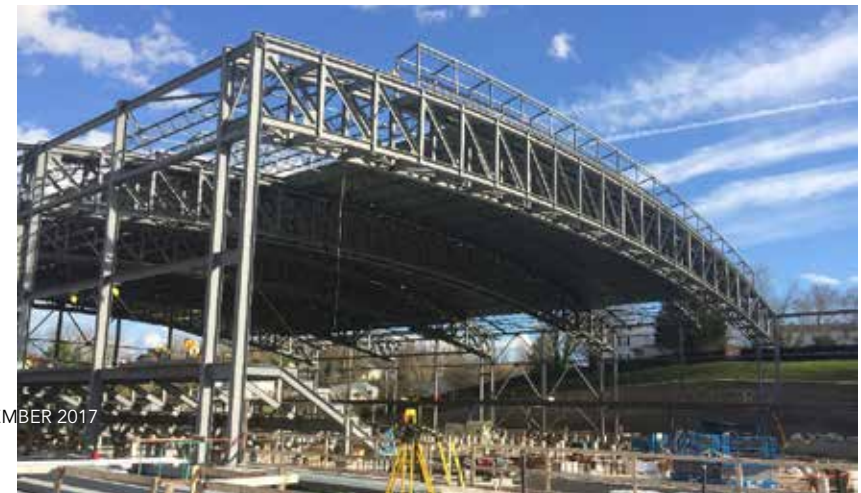
▼ A roof truss, prior to erection.



▲ The approximately 405-ft-long building is laterally supported by steel braced frames along its perimeter.

▼ The roof apex is 60 ft above the main floor.

▲ ▼ The roof framing has a discrete system of horizontal bracing in plane to form a diaphragm, consisting of double angles, and distribute lateral loads to the perimeter braced frames.



complexity of the connection detailing, it successfully joined the two trusses together.

Each truss has two platforms cantilevered off the truss bottom chord. These platforms are used to access the ropes course from the truss elevation and impose eccentric concentrated loads on the trusses. Maintaining a strong and stiff box-shaped section was essential to efficiently resist the eccentric and unbalanced roof loading on the trusses.

Success in Collaboration

Early communication between the project team benefited the design and construction of the structural box trusses. Using moment-connected box trusses not only provided catwalk access for the high ropes course, but also provided stability during erection. This eliminated the need for external stability bracing during construction, reducing time and cost. The trusses were designed in six sections with bolted splice locations along the length. The sections were delivered to the site prefabricated and were assembled on the ground and lifted into place on the double-column supports.

Successful coordination between disciplines aided in providing box trusses that achieved the desired structural strength, constructability, flexibility of use and aesthetics. The use of structural steel provided the flexibility needed to create a column-free space that could support the facility's unique amenities. Collaboration and flexibility made it possible to construct such a facility—the largest of its kind anywhere—and one that allows for such a unique interaction between the structure and its users. ■

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