



# Connecting on Campus

BY JAMES POSPISIL, P.E.

## A new exposed steel pedestrian skyway links two parts of the Duquesne University campus.

**DUQUESNE UNIVERSITY** is situated on an urban campus in the Hill District of Pittsburgh. Bound on the south and west by a formidable cliff and the north and east by city streets, the university has faced challenges in meeting the growing need for new facilities.

This January, a new multi-purpose facility with a ballroom, fitness center, and retail space for the university was completed north of campus across Forbes Avenue. During the initial planning phase for the new building, a pedestrian skyway was envisioned to connect the parking garage and main campus to the new building. The skyway would improve student access to the new facility by creating a safe way to cross the street, and would also function as the primary conduit between the new building and the central campus steam, chilled water, and telecommunications infrastructure. In addition, the skyway would serve a symbolic function as well, as a gateway to the campus and Hill District. Construction of the skyway would take place concurrent with that of the new building, due to the critical nature of the infrastructure connections, and a total of nine months was allotted for building the skyway.

During the schematic design process

for the skyway, the idea of using an exposed structural steel frame was conceived. The ability to prefabricate most of the structure either in the shop or near the site allowed the design team to resolve construction difficulties related to the small site and accelerated the construction schedule. Architecturally exposing the steel simplified many details while mirroring existing architecture on campus and highlighting the steel heritage of Pittsburgh.

### Constructability Challenges

A key parameter affecting many aspects of the design was the city's desire to limit ongoing closures to Forbes Avenue to one lane and total closure of both lanes to one weekend. In addition, the close proximity of the parking garage to the south and ongoing construction of the new building to the north added to the complexity. With only one lane of Forbes Avenue accessible for construction, and a minimal lay-down area between Forbes Avenue and the parking garage, careful planning and extensive prefabrication were necessary.

Critical splice locations were identified to maximize shop prefabrication. To eliminate the need for long-term street closures, the center 74-ft portion of the bridge span

would be prefabricated near the site in one lane of Forbes Avenue while the towers and 14 ft of cantilevered bridge span were being erected on each side of the street. Erection of the center portion of bridge would occur in a single lift on a single weekend.

During the tower assembly process, plumbness was maintained to within  $\frac{1}{4}$  in. to ensure that the prefabricated center span would fit. Erection of the center span was planned for early morning so it could be installed "cold," reducing thermal growth and minimizing the overall length. To keep the visible connections clean, only  $\frac{1}{2}$  in. of shim space was provided at each end of the center span, allowing for tower plumbness and center span length tolerances of 1 in. maximum. The total time needed to erect the steel frame was approximately four weeks.

### Trussed Towers

The primary structural components of the skyway include trussed towers on each side of Forbes Avenue, with a central Vierendeel truss span partially supported by two tapered plate girder arches. The trussed towers measure approximately 16 ft by 16 ft and have a network of rod and clevis X-brace assemblies providing stiffness and sta-



**Above:** One inch was allowed for tolerances when erecting the prefabricated center span.

**Right:** The tower columns support the pedestrian bridge; access to the bridge occurs through the adjacent structures.



bility. The south tower is more than 140 ft tall, while the north tower is 100 ft tall.

In each tower, horizontal X-bracing levels occur every 19 ft and are comprised of 2-in.-diameter 36 ksi rods with a #5 clevis and 2-in.-diameter pin at each end. Three horizontal bracing levels occur between the ground and the bridge deck. Vertical X-bracing consisting of 2-in.-diameter 50-ksi rods with a #8 clevis and 3-in.-diameter pins occurs at every level except the street. To fully develop the higher strength vertical rod bracing, up-set threaded ends were specified at the clevis connections.

Tower columns are made up of multiple HSS 10x10x $\frac{3}{8}$  members with HSS 16x8x $\frac{3}{8}$  horizontal members passing between at the bracing levels. To allow for pedestrian access to the garage and new facility, vertical X-bracing was omitted on the first level. Here, at the weakened story, each tower column was made up of four HSS 10x10 members acting as a moment frame. Between the first braced level and the bridge deck, the tower columns were reduced to three HSS 10x10s, and above the deck they were further reduced to two HSS 10x10s. The column reductions could occur above the first braced level because the towers behave more like a truss. The HSS 16x8 horizontal members passing between the column groups at the tower corners are spliced with end plates at the center. This detailing approach allowed for the complicated welded connections at the columns to be performed in the shop, while simpler bolted end-plate connections were used in the field.

The concrete bridge deck is approximately 75 ft above the street and is sup-

ported by a walkthrough Vierendeel truss with intermediate ties to the tapered plate girder arches. The chords of the Vierendeel truss are made up of continuous W14 members. Vertical truss elements are HSS 10x6x $\frac{1}{2}$  with bolted end-plate moment connections to the truss chords. The tapered arches, while aesthetically important to the architecture of the bridge, are structural in nature. They provide intermediate support to the Vierendeel truss and add significant lateral stiffness to the structure by functioning like a knee brace between the bridge

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and the towers. The total span of the arch and truss system between the towers is 102 ft, and approximately 240 tons of structural steel were used in all.

#### Foundation Stability

With the structural concept and basic construction sequence in mind, detailed analysis and design of the individual framing components and subassemblies was performed. The structure was analyzed as three individual subassemblies: the north tower and cantilever, the south tower and cantilever, and the center bridge span. Construction and environmental loads were considered, and the three primary subassemblies were evaluated for member stress

and overall stability. After evaluating the subassemblies, the structure was evaluated as a whole. A three-dimensional finite element model considering wind, seismic, live, and temperature loads was used to verify member stresses and structure deflections.

Due to the height-to-width ratio of the trussed towers and the concentration of lateral load more than 75 ft above the base, very large overturning moments are present at the foundations. Further complicating the foundation design were the physical constraints imposed by the existing parking garage at the south tower and new building at the north tower. Different foundation systems were chosen for each tower to accommodate the specific design requirements.

The south tower used a spread footing bearing on shallow bedrock. Because the existing parking garage foundations were within inches of the new tower, overturning resistance of the foundation could not be achieved by using a large footing. Taking advantage of shallow competent bedrock, a permanent post-tensioned rock anchor system was chosen to achieve overturning stability. A total of six 150-kip rock anchors were used to anchor the foundation to the bedrock. The post-tensioning force and anchor layout were chosen so the footing would be in constant contact with the bedrock, even under the extreme overturning load.

At the north tower, lower bedrock and the concurrent construction of the new building resulted in a much different foundation design. To resolve the overturning forces, an aggregate-filled concrete ballast



Steel rods and clevises provide visually unobtrusive lateral bracing for the supporting towers.

box was designed. The ballast box is supported by caissons founded on bedrock and was configured so that the new building could be constructed without affecting the stability of the tower. The weight of the box was used to resist overturning

forces; therefore, rock anchorage was not required.

The superstructure-to-foundation connection involved transferring moment and shear in both directions in combination with vertical load either up or down. A non-bonded post-tensioned anchor bolt system was chosen to simultaneously resolve all loads. Post-tension forces were chosen to achieve a constant minimum contact pressure between the tower base plates and the concrete piers, eliminating cyclical loading on the anchors while maintaining enough contact pressure to resist shear through friction. A total of eight anchors were post-tensioned to 50 kips at each tower column. After tensioning and testing, the anchors were grouted, and custom steel anchor caps were filled with grout and welded into place to protect the anchor heads.

### Successful Skyway

The successful completion of Duquesne University's skyway was due in large part to early interaction between the design team and the steel erector and contractor. With input from each entity, critical construction issues were raised and addressed while the design was in the early stages. Practical solutions to anticipated construction

problems were identified by the design team and integrated into the structural and architectural concept for the skyway. And of course, success was also the result of the design flexibility afforded by exposed structural steel.

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