BINGHAMTON UNIVERSITY ENERGY R&D BUILDING

This is the first article in a two-part series and highlights the development and design of the building. The second article will be presented in a future issue and will focus on the fabrication and erection.

By Chris Latreille, P.E.

A new 105,000-square-foot Energy R & D building is currently under construction at Binghamton University in Binghamton, New York. It represents one of a series of laboratory research facilities planned for the university. This $45 million research facility will house physics and chemistry programs focused on energy technologies of the future.

The extensive use of curved, round HSS members as a structural framing system and the primary visual components of the architecture are what makes this project unique. Use of BIM was essential to creating and visualizing the many complex shapes needed to model each element and produce the Construction Drawings. Autodesk Revit was used as the BIM platform.

The building consists of four distinct programmatic components (*Figure 1*): two laboratory Pods, an Atrium between them, and a Link rotunda structure that connects the new facility to the recently completed Center of Excellence (COE) to the east. Laboratory Pods D and E continue the research block programming of the COE, which houses Pods A through C.

The design and construction of the building is broken up in to two phases; the first is the majority of structure and the second is the architectural fit-out, exterior skin, MEP systems, final site design, and landscaping. Phase 1 construction is mostly complete and should be finished during this summer, 2015. Phase 2 will commence in late summer 2015 with a targeted completion in late 2016.

The building is steel-framed and has a full concrete basement. The foundations consist of concrete spread footings bearing on glacial till. The three-story Pods form the largest features of the building and consist of conventional steel framing and composite slab construction. The Pods are braced by moment frames in each direction, and portions of the first floor for each Pod were designed for floor vibrations due to human activity. Pod D and the Atrium are 7 feet higher at each level than Pod E. Pod D is also offset 45 degrees with respect to Pod E, creating the triangular-shaped Atrium that separates them.

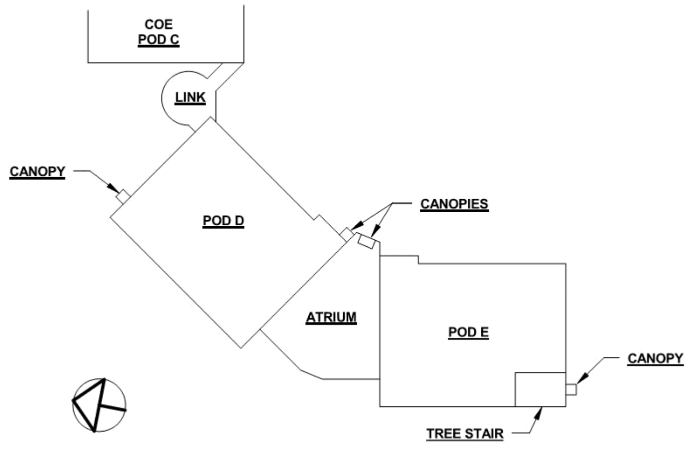

Figure 1. Key plan.

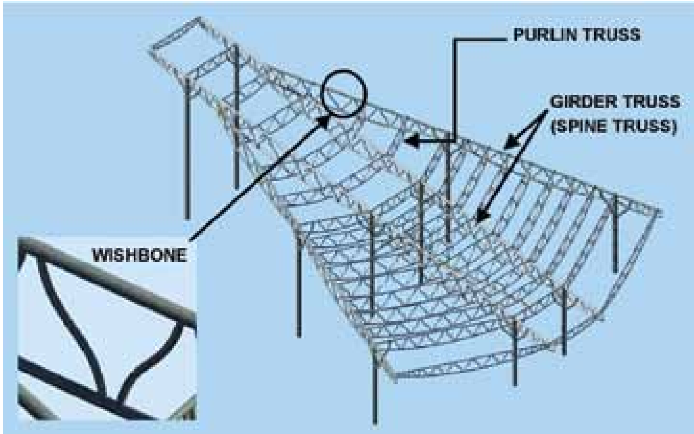

Figure 2. Revit rendering of full atrium roof.

Atrium Roof

The use of curved round HSS began in the Atrium. The Architect modeled a fan-shaped space with a mono-sloped roof between the Pods. This clerestory space is tall on the east side and slopes down almost 30 feet to the west. The roof is symmetrical about a centerline running east to west, and the north and south edges of the roof splay out at an angle of 22.5 degrees along the walls of each Pod.

One of the Architect's initial goals was to expose a structure that would create visual interest from both the interior and exterior. The desired openness of space ruled out the use of numerous columns and diagonal bracing for lateral resistance. The Structural Engineer (SE) could only locate one line of columns at the interior of the Atrium. The Architect envisioned the rest of the columns supporting the east and west ends of the roof to be exterior to the glass window walls with large roof overhangs beyond the glass façade.

Based on these criteria, it was evident that a structure consisting of moment frames for lateral resistance was needed. The geometry was created in Revit using round HSS. The idea behind the development of the geometry was an organic theme that fits with the "smart energy" initiatives of the facility. The Architect stipulated the guiding principles and overall massing of the space for the design, while allowing the SE the freedom to develop the structural concept and geometry based on the vision of his aesthetic and the SE's knowledge of what is structurally feasible.

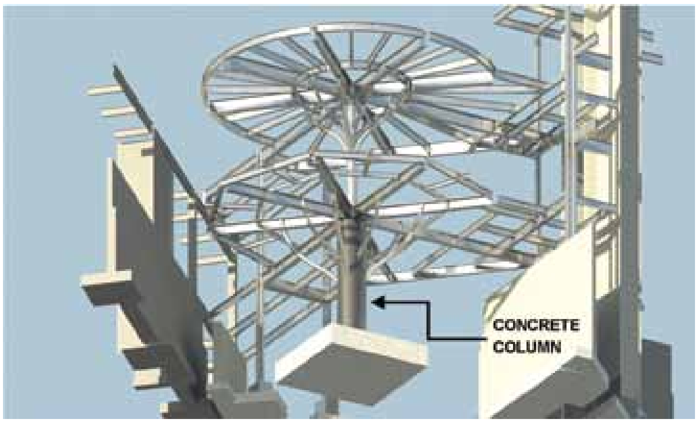

Figure 3. Revit rendering of Link rotunda.

The framing layout consists of purlin trusses supported by girder trusses or "spine trusses". Both types of trusses consist of a straight top chord and curved bottom chord. The web members consist of double-curved round HSS giving the appearance of a series of wishbones, which led to the predictable nickname "wishbone truss." The web members are separated by 8 inches, center-to-center at connections to top and bottom chords (*Figure 2*). This was done for appearance but also to eliminate highly skewed intersections of web members and complicated welding. The web members intersect the chords at 90 or near-90-degree angles and are separated enough to allow for all-around welding. Welding was preferred early on for appearance but also for transfer of large forces, particularly at chord members.

The top chords of the spine trusses frame over the tops of the columns, and the curved bottom chords intersect with the shafts of the columns below the top. This was done to simplify the connections and to create the necessary frame action needed for lateral resistance. The purlin trusses are top chord bearing with discontinuous bottom chords.

From a design perspective, the trusses function as modified Vierendeel trusses and each web member must accommodate bending, axial, and shear forces. Since the members are curved, the axial forces also induce additional bending away from the connections to the chords. An elevation was created for each truss profile in Revit, and the wishbone members were modeled with splines and adjusted using detail lines laid out with the desired geometry. The spine trusses at the center of the Atrium were the starting point for spacing and sizing the wishbones, and locating purlin truss bearing points. The geometry of the spine trusses along the Pods was determined using similar triangles based on the 22.5 degree offset. Luckily the symmetry of the space allowed for a lot of mirroring, which reduced modeling time. More purlin trusses were required at the west side of the Atrium due to longer spans and drifted snow loading.

The sequence of analysis included exporting the Revit truss profiles to AutoCAD in order to locate four or five nodes along the length of each wishbone web member. The AutoCAD geometry was then exported to RISA 3D to perform 2D analysis to get initial member sizes based on gravity loads. The profiles were then assembled into a RISA 3D model for the entire structure, including the columns. The final model took about three hours to run all of the load combinations.

There are 10 columns that support the Atrium roof. Each has struts that are double-curved, similar to the web members of the trusses. The struts or "branches" intersect with the top and bottom chords of the trusses, providing vertical support and also enhancing the frame action and stiffness of the system. It is no surprise that the nickname "tree column" was born.

The truss connections are generally all welded. However, six of the ten tree columns, eight purlin trusses, and portions of the spine trusses are outside of the building envelope. Welded joints at the envelope boundary would create large thermal bridges which, if nothing else, seemed contrary to the spirit of a "Smart Energy" facility. As such, custom bolted splices were designed and detailed that utilize thermal isolation material (TIM) and stainless steel bolts. The roof deck is also broken at the envelope boundary and utilizes similar connections to reduce thermal bridging. This technology was used at other locations in the Pods and Link. Hot-dip galvanizing was specified for all steel outside of the building envelope.

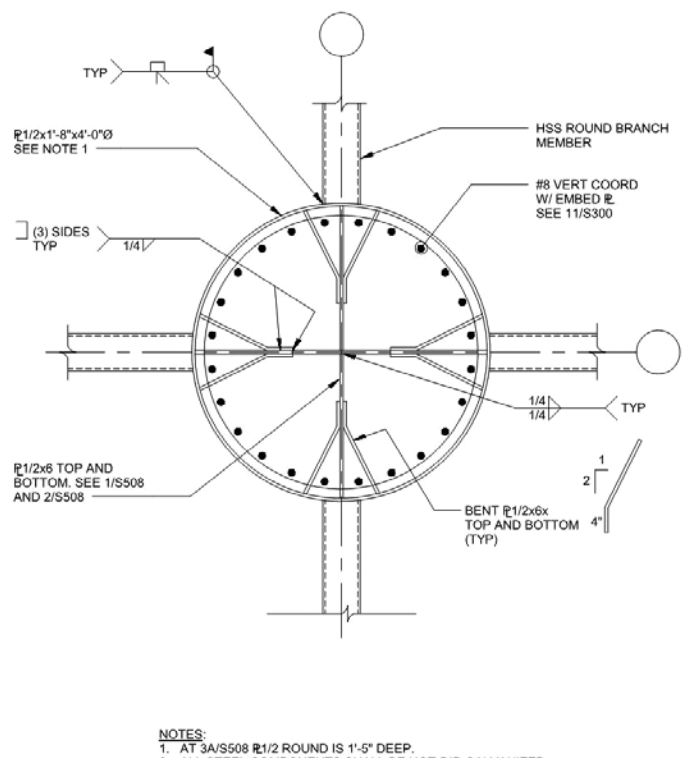

Figure 4a. Structural detail of Link collar.

Link Rotunda

The 40-foot-diameter rotunda continues a theme prevalent at other buildings on campus. However, this one is unique in that it is supported by a single 4-foot-diameter concrete column below the floor and a single 18-inch-diameter round HSS tree column above extending to the roof. The branches of the tree column are double-curved, similar to the tree columns in the Atrium. They are set at two elevations using two different round HSS sizes and are offset in plan by 45 degrees.

The branches of the columns primarily carry gravity loads for the floor and roof at each level, but also provide frame action to resist lateral drift. Lateral drift was a concern in design since lateral deflection in the column is magnified as vertical deflection in the floor and roof framing. It was necessary to analyze the rotunda as an inverted pendulum structure due

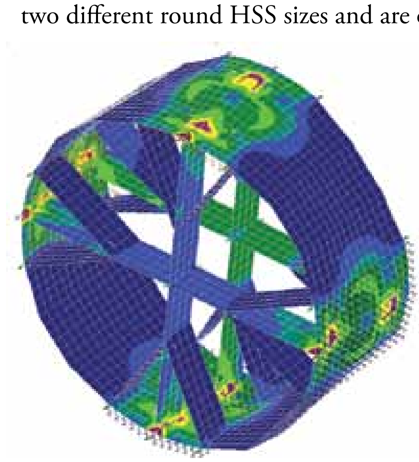

Figure 4b. FEM results from RISA 3D.

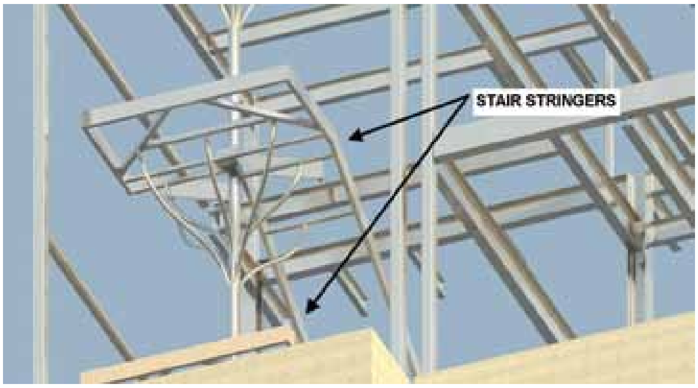

Figure 5. Revit rendering of Tree Stair.


Figure 6. Revit rendering of east entrance canopies.

to the lack of redundancy with the single column support. As such, the seismic forces used for design were three times higher than other parts of the building due to the reduced response modification factor. Part of the solution for controlling deflections was to create a hub of moment connections for all beams framing into the tree column at the roof and floor. Even though the branches carry a large amount of vertical load, the moment connections reduced the hinge effect at the hubs producing lower deflections.

The framing for the Link connects into the northeast corner of Pod D, which is structurally isolated from the rest of Pod D above the first floor. This corner consists of a stair with a concrete wall running up through the middle between flights and a concrete elevator shaft. These concrete elements provide the rest of the lateral resistance for the Link. The stair stringers form drag struts connecting the Link floor and roof framing to the concrete walls. There is another expansion joint northeast of the rotunda, and a small bridge connects back into Pod C of the COE building.

The tree column for the Link is interior, and the concrete column below is exterior. A large TIM plate was detailed between the leveling plate and base plate to reduce thermal bridging. The connection of the branches for the interior steel column are similar to the Atrium. Connecting the steel branches to the concrete column proved challenging since the connections are structural and are exposed. Several options were considered, including individual embedded plates for each branch and embedding the bottom section of the round HSS in the concrete. However, it was determined that the individual plates would have been difficult to place and secure, and there was also concern about the logistics of building forms and consolidating concrete around all faces of an embedded branch member while avoiding chips and spalling. The solution was a custom galvanized steel collar embedded in the concrete column at two levels to support the two offset sets of curved branches that are welded to it. The collar is connected with internal tie plates and skewed reinforcing plates for areas of high stress.

Tree Stair

The southwest corner of Pod E features another prominent entrance that is highly visible from the adjacent road. To provide continuity with the aesthetic of the Atrium and the Link rotunda, the design team decided to incorporate another structural tree element into the two-story staircase at the entrance.

The stair stringers consist of HSS rectangular members supported by floor framing at each floor. At the intermediate landings, a single, round HSS tree column provides support for the landing and stringers. The branches serve a similar dual purpose of carrying gravity loads from the stringers and landing framing while providing frame action to laterally brace the entire stair system.

Exterior Canopies

The canopies are the only ornamental steel component relegated to Phase 2. There are a total of four canopies; two at the main (east) entrance of the Atrium, one at the southwest corner of Pod E near the Tree Stair, and one at the northwest corner of Pod D for an exit.

The canopy steel mimics the organic theme of the Atrium and Link rotunda, incorporating wishbone elements and tree columns. The canopies are structurally separate from the building wall and are supported by only two columns each. The structural steel for the canopies will be highly visible from all vantages as they support large sheets of 1-inch-thick glass as the roof deck. Hot-dip galvanizing was specified for all canopy steel.

For the Structural Engineer, the design and development of these unique components was a rare opportunity to balance form and function while staying true to the mission of the research goals of the facility. The Binghamton University Energy R & D Building will be a welcome addition to the campus. Stayed tuned for Part 2.▪

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Project Team

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Architect: William Hall, Binghamton University, Binghamton, NY
General Contractor: Fahs Construction Group, Binghamton, NY
Structural Steel Fabricators: Schenectady Steel, Schenectady, NY and JPW Companies, East Syracuse, NY