STEEL TUBE INSTITUTE

HSS CASE STUDY

ALLIANZ FIELD – A MODERN STADIUM MARVEL IN ST. PAUL

By Cathleen Jacinto, PE, SE

Photo Credit: James Ewing

"THE BUILDING IS LIKE WATER FROZEN IN MOTION."

– Phil Kolbo, Populous

Structure type: Stadium
Location: St. Paul, Minnesota
Completion Date: 2019
Project Size: 346,000 SF

PROJECT TEAM

Owner: Minnesota United Football Club

Construction Manager: Mortenson Construction

Architect: Populous

Structural Engineer and Enclosure Engineer: Walter P Moore

Steel Fabricator: Merrill Steel

Steel Erector: Danny's Construction

Bender Roller: Max Weiss Co.

Fabric Contractor: Enclos Tensile Structures (Formerly Pfeifer/FabriTec Structures)

Steel Connection Engineer: Computerized Structural Design (CSD) Structural Engineers

Approaching Allianz Field at night, its transparent enclosure backlit by curved glowing blue lines makes a striking impression. Home to the Minnesota United FC professional soccer team, Allianz Field is a dynamic structure for the city of St. Paul, Minnesota. With 4,500 total tons of steel in the stadium, HSS is the key structural member supporting the iconic fabric cladding. HSS also supports the stadium's 360-degree cantilevered canopy, braced frames, and exterior building columns around the perimeter of the stadium. To learn how integral HSS is to the design of this structure, we spoke to lead members of the Allianz Field design and construction teams (summarized below) and gained insight into how this impressive stadium was brought to life.

Contributions to this case study were made by:

- **Structural Engineer:** Justin Barton
  Walter P Moore (WPM)
- **Architect:** Phil Kolbo, Populous
- **Steel Fabricator:** Fred Schwalbach and
  Andrew Huebner, Merrill Steel
- **Bender Roller:** Alan Sanders, Max Weiss Co.

INNOVATIVE CLADDING DESIGN

Allianz Field is surrounded by an exterior skin façade that is the iconic feature of the stadium. Inspired by Minnesota's cold climate and as the "Land of 10,000 Lakes," the stadium sought to articulate water frozen in motion, according to architect Phil Kolbo. This theme of water is manifested by a translucent fabric over undulating blue lines curving around the stadium's perimeter. Technically speaking, the enclosure consists of a translucent PTFE (polytetrafluoroethylene) tension fabric with lamination and is supported by curved steel HSS members.

The design vision was to provide a continuous fabric cladding which called for the façade structure to resist thermal expansion rather than introducing expansion joints. It was a challenge to find a precedent for a project utilizing a similar large, continuous fabric enclosure, especially where the defining façade structure intersected with itself. The design team collaborated with the fabric contractor Enclos/FabriTec to ensure appropriate support for this innovative cladding system. Kolbo described the collaboration, "Our team's close collaboration across Populous, Walter P Moore, Enclos and other consultants allowed us to push the boundaries of typical engineering and fabrication methods as it applies to architectural membrane design."

According to Engineer of Record, Justin Barton, the PTFE skin is a fabric that is tensioned and clamped to its HSS supports. He referred to these HSS members as driver pipes as they drove the overall geometry of the enclosure. Barton likened the enclosure's behavior as that of a fabric sheet tensioned and spanning between its HSS supports.

Photo Credit: Walter P Moore

"...THIS PROJECT WAS EXTREMELY FAST FOR US. WE WORKED ON IT FOR SEVERAL MONTHS AND IT WAS ERECTED IN 60 DAYS... "

– Fred Schwalbach, Merrill Steel

When wind loads hit the fabric, the tension fabric will pull where it connects to the intermediate support members. The push of the wind load and pull of the fabric results in bending in two directions at the HSS supports. Barton explains that the HSS members resist loading from different directions and bend about two axes. These two axes in turn also rotate in a corkscrew effect along the length of the HSS at the attachment points from the fabric enclosure.

Barton expressed, “Having a round shape with a capacity for bending loads in both directions was ideal. We really didn’t even look at anything else besides round HSS for those members. The round shape truly met all the needs that we were looking at. Use the right material for the right job. Having the round HSS around the exterior of the building was the exact right material and the perfect application for that.”

HSS SPECIFICATION AND FINISHES

The round HSS supporting the enclosure were typically 16” diameter, ASTM A500 Grade C. At the time of the project, the yield strength for the A500 Grade C HSS was 46 ksi. There were also a few areas where rectangular HSS members were utilized, also with A500 Grade C steel, with yield strength of 50 ksi.

All exposed steel on the project received a two-part performance paint system coat, which included a zinc rich primer and a polyaspartic topcoat specifically for the round HSS supporting the cladding. According to Huebner from the Merrill fabrication team, the zinc rich primer selected for the HSS members was Amercoat 68 HS and the topcoat was a polyaspartic coating called PPG Kwikspar 600. The design team was mindful of the challenge to maintain and repaint the HSS members over the course of the lifetime of the building, so the architectural team specified the higher-grade, extended length topcoat. The topcoat selected solves the problem of breakdown in ultraviolet conditions with the intent to last an extended period of time, while also meeting aesthetic standards. Merrill possesses the highest coating AISC endorsement and were equipped to apply this high quality primer and topcoat. In addition, the design team developed specific criteria for the exposed HSS steel such as locating HSS weld seams away from view.

“THERE WAS NEVER ANY DEBATE AROUND THE PRIMARY MEMBER SHAPES; HSS WAS THE ONLY WAY WE COULD ACCOMMODATE THE MYRIAD ANGLES AND CONNECTIONS NEEDED TO CREATE SUCH AN ICONIC DESIGN.”

– Phil Kolbo, Populous

THERMAL CONSIDERATIONS

In addition to wind loading, thermal expansion needed to be addressed in the design of the continuous steel HSS at the perimeter. The design team worked to determine the thermal expansion coefficients of the specific fabric selected for the project. Since the PTFE fabric consists of a mesh with a lamination on top of it, it is different from typical PTFE fabric and is more stiff, which played a factor in its thermal expansion. Kolbo stated, “We had engineers on the construction side, engineers on the fabrication side, and then we have our own engineers with Walter P Moore. Three brain trusts were in the room to figure out these things that the fabric industry hadn’t had to consider yet, and everyone was on board.”

Barton likened these continuous members as acting like a giant rubber band. In warm summer weather, the HSS will gain heat and likely expand. In the Minnesota winters, they tend to shrink and contract. In order to avoid expansion joints in the building skin, the continuous HSS supports and their end plate connections were designed for the cumulative effect of thermal stresses.

ROUND HSS CONNECTIONS

The round HSS were made continuous throughout the perimeter of the stadium by the use of end plate moment connections. These connections resist gravity, flexure, and axial forces while achieving a continuous steel element at the perimeter. The continuity provided in the moment connections alleviates the need to design for large positive moment between column supports and helps to control deflections. The same end plate connection was provided throughout the stadium to simplify fabrication and erection. In addition, the ends of the HSS were cut to a certain angle and the end plates fitted to maintain the correct overall member curvature through the connection joint.


Photo Credit: Walter P Moore

"WE REALLY DIDN'T EVEN LOOK AT ANYTHING ELSE BESIDES ROUND HSS FOR THOSE MEMBERS."

– Justin Barton, WPM

In addition to the HSS-to-HSS connections, the connections between the fabric enclosure and the round HSS were also carefully coordinated. The fabric cladding was clamped to built-up T-shape plates attached to the perimeter HSS. Barton describes that the T-shape standoffs were not always in a straight line along the length of the HSS but were placed in a corkscrew effect roughly every 3 ft around the HSS. The round HSS shape was critical to this corkscrew detail, and the detail would not have worked with another shape such as a square. Kolbo described that an iterative process between Populous and Walter P Moore was performed to ensure the location of each T-shape attachment adequately supported the fabric, with feedback from the fabric contractor. The result of this collaboration was a BIM model that located the centerlines of each T-shape fabric attachment on each HSS member. This front-end coordination done by the design team to locate each fabric attachment allowed for a more streamlined steel fabrication and detailing process.

In addition, the same T-shape plates were used throughout the project, also easing fabrication. It was quite an accomplishment for Merrill Steel to fabricate and lay out the T-shaped pieces properly, at each point along the length of the HSS, in order to achieve the required curvature of the tension fabric enclosure.

FABRICATION AND BENDING HSS

Each HSS at the perimeter was bent in only one direction and curved to only a single radius. Care was taken not to specify double curvature in the HSS members. However, in order to meet the overall desired curvature of the stadium perimeter, nearly every round HSS on the project has a different radius than the HSS members adjacent to it. Although each HSS was curved to a different radius, there was still only a single radius to each piece, which helped to ease fabrication. This single radius was critical because as Barton described, "...while it looks complex, it's actually a series of fairly simple pieces that I'll just build up together to make something that looks incredible."

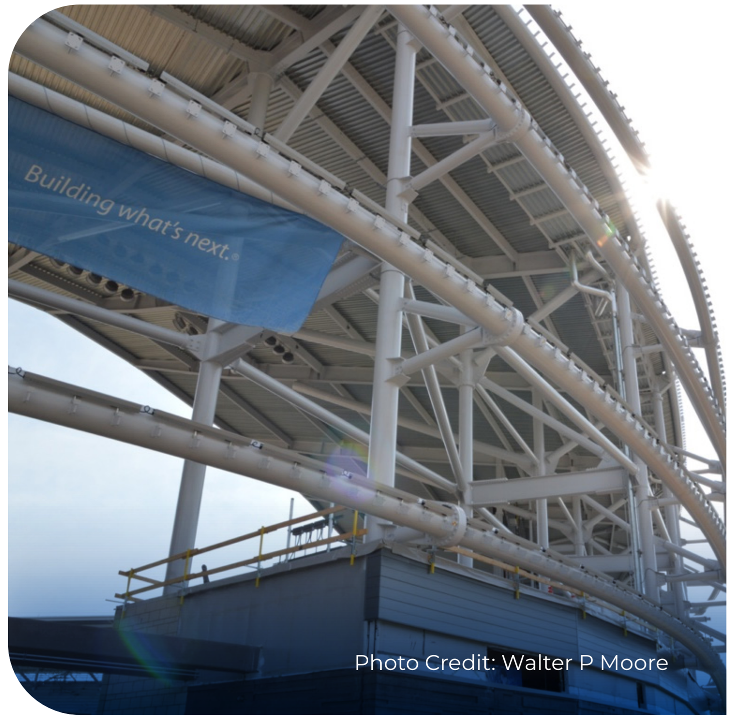

Photo Credit: Walter P Moore

Although no two radii were the same on the project, curving of the HSS pieces went smoothly, according to Alan Sanders from bender roller Max Weiss Co. Cold bending processes were utilized to achieve the desired radius for each HSS piece.

"...WHILE IT LOOKS COMPLEX, IT [HSS] IS ACTUALLY A SERIES OF FAIRLY SIMPLE PIECES BUILT UP TOGETHER TO MAKE SOMETHING THAT LOOKS INCREDIBLE."

– Justin Barton, Walter P Moore

Fred Schwalbach and Andrew Huebner from the steel fabricator firm, Merrill Steel, further clarified that in addition to the single radius curve, the HSS was pitched as well, resulting in compound angles. In addition, members framing into the round HSS members required profiling around the HSS. The connecting ends of each round HSS member also needed to be indexed relative to the curve and pitch of each member. This was done by first laying each curved HSS piece flat. Then they would tip the HSS piece into a plane based on where the member would be located on the exterior façade. This clocking, or indexing, of the HSS pieces was important in fabricating the HSS connections. A good deal of pre-planning was required to ensure smooth erection. According to Merrill, 75% of the project was fabricated and staged for shipping before erection started. The front-end coordination proved successful as there was only one

HSS piece that needed to be fixed, out of 1300 shippable HSS pieces. Erection of steel spanned over 60 days. This level of success is rare on such a complex project, and is a testament to the level of communication between the project teams.

"THERE WAS ONLY ONE HSS PIECE THAT NEEDED TO BE FIXED, OUT OF 1300 SHIPPABLE HSS PIECES."

– Andrew Huebner, Merrill Steel

Tolerances between the cladding and steel systems were also a critical coordination item. There were tight tolerances in the fabric, as well as its attachment to the HSS and its T-shaped plates. Merrill explained that permissible mill tolerances and erection tolerances have the potential to stack up, so they worked closely with their connection engineer, CSD Engineers, to develop erection sequencing that was mindful of tolerances and minimized potential for misaligned connections. Control points were established along the structure to allow for relief and to accommodate shims for fitup. The fabric installer and the steel fabricator coordinated both systems closely to ensure the final product fell within appropriate tolerances.

OTHER TUBULAR MEMBERS IN THE STADIUM

Apart from the innovative cladding support, tubes are also utilized to support the cantilevered canopy serving to shelter its occupants from inclement Minnesota weather. The canopy strut is primarily in pure axial compression, one of many loading conditions ideal for a tubular application. Canopy struts used on the project consisted of seamless large-diameter pipe, API 5L X-52, with a higher yield strength of 52 ksi.

HSS were used in the braced frame systems as well as exterior building columns at the perimeter of the stadium. The architect desired smooth lines for the building columns, making round HSS an optimal choice. The round shapes were also ideal in providing axial capacity at longer unbraced lengths. Barton expressed, “We’re able to really get some longer unbraced lengths out of the columns for not much of a weight premium than we would have compared to some other systems.”

Photo Credit: Walter P Moore

Photo Credit: Walter P Moore

DESIGN AND CONSTRUCTION TEAM COLLABORATION

The success of this stadium was due in large part to the effective collaboration between the several design and construction teams involved - architect, owner/developer, structural engineer, contractor, steel fabricator, roller bender, fabric contractor, lighting teams, and more. As one can imagine, the location of the HSS members, its T-shaped standoffs, and fabric cladding needed to be precisely coordinated along the 88,000 square feet of area of the PTFE skin. One of the first steps to achieving this coordination was the use of shared digital platforms - Grasshopper, Rhino, and Revit - between architectural and structural teams. This was then shared with the fabricators to build into a Tekla model and allow for rapid iterations as needed to accurately control the enclosure geometry. Barton explained that the design teams could adjust the geometry as needed during construction to avoid overstressing or under-tensioning the fabric, and ensure an undulating geometry throughout. In addition, the structural team was involved early in the concept phase when numerous design options were in consideration, to help to craft and support the structure.

According to Schwalbach, the BIM model their fabrication team received from the design team was a large reason for the success of the steel fabrication for this project. The engineer’s BIM model contained full structural member geometry and the centerline location for each T-shaped attachment, for which there were thousands of attachments required. The fabrication team could rely on the BIM model’s level of accuracy provided by the design team, allowing them to focus on detailing and indexing each steel piece and its attachments. Schwalbach describes, “Had the engineer, architect, and the PTFE provider not taken that step to develop that better-than-traditional [BIM] model, the burden would have fallen on Merrill. So the architect, the engineer, and the PTFE provider being able to get out ahead and get that kind of critical component established and turned over to us, that really allowed us to get out of the gate." Overall, the efficient process leading to the final solution was a true team effort.

From its innovative cladding, merging fabric and steel, to its resilient canopy, Allianz Field is an architectural, engineering, and fabrication feat. Integral to each unique aspect of this stadium, HSS plays an essential role in bringing this impressive structure to life.

For additional information on Allianz Field, see Justin Barton's STI peer article here.

Photo Credit: Walter P Moore

"IT'S NOT UNCOMMON TO FIND BOTH ROUND, RECTANGULAR, AND SQUARE HSS MEMBERS IN STADIUMS. BUT THE FACT THAT THIS WAS IN THE CONFIGURATION AND THE SHAPE THAT IT WAS IS REALLY KIND OF UNMATCHED TO OTHER PROJECTS THAT WE'VE SEEN OF THAT SIZE AND MAGNITUDE."

– Andrew Huebner, Merrill Steel

REFERENCES:

1. https://www.mnufc.com/stadium/about/

2. https://www.youtube.com/watch?v=EoDE0VJosK0&list=PL3JX-CHcuekX0i68NNqIJi0N3AIl3MqxA&t=146s