The new Seattle, Washington headquarters campus for the world’s largest philanthropic organization targets aggressive sustainable performance with maximum transparency by utilizing curtainwall and specialty-glazed structures. A transparent glass atrium serves as the primary entry, centrally located and programmatically versatile with grandeur to host receptions, banquets or other events.

The atrium features two custom point-clamped glass walls supported by a series of slender vertical cables, elegant by design and innovative in their responsiveness to programmatic demands, climatic context and an aggressive project schedule. The lantern-like portal acts as a fulcrum between indoor and outdoor space, while establishing a strong connection to the immediate public realm and emphasizing the benevolent character of the Foundation. The atrium’s point-supported approach minimizes thermal bridges within the envelope and exemplifies the degree of high-performance that can be attained outside the traditional curtainwall facade paradigm to achieve a transparent environment with sustainable priorities.
INTRODUCTION

The Foundation currently has more than 900 employees working in various locations. Looking to unite locations and increase capacity to 1,500 employees, the Foundation conceptualized a new sustainable campus located in the heart of Seattle which reflects their values and mission. The first phase broke ground in July 2008 and includes the construction of two sweeping boomerang-shaped six-story structures, resulting in 800,000 square feet of office, event and visitor space. Phase One was completed in spring 2011. A third building will be constructed in a second phase, adding 400,000 square feet. Utilizing a whole-building approach for Phase One, the project team was able to achieve a balance of transparent aesthetics and sustainable performance by evaluating the enclosure conceptualized a new sustainable facade program includes in excess of 300,000 square feet of surface area, requiring the highest level of craftsmanship throughout every aspect of construction. The atrium’s tensioned structure, in combination with high performance argon-filled insulated glass units, is an example of how facade and mechanical engineers can collaborate to leverage the thermal advantages of point-supported systems — in comparison to conventional curtainwall systems — to attain aesthetic and aggressive sustainable performance goals.

SITE CONTEXT

The Foundation sits on a 12-acre pentagonal site in the backyard of Seattle’s iconic structure, the Space Needle. The site, formerly a city-owned and operated parking lot, is located adjacent to Seattle Center, a cultural center with a storied history of regional and international gatherings. The site is well connected with the metro transit system, including bus stops along the southwest, atop the Space Needle experience deck.

Figure 1. Aerial view of the Foundation headquarters under construction. Photo taken from the southwest, atop the Space Needle observation deck.

The atrium’s glass includes a low-e coating applied to the inner surface of the outermost pane (number 2 surface) to provide solar control and moderate the visible light transmittance characteristics with a relatively color-neutral coating. These insulated glass units with low-e coating and argon gas fill are designed to reduce heat loss but permit solar gain — a solution most appropriate for a heating dominated climate such as Seattle. The extensive use of low-e glass with argon fill throughout the project was critical in meeting the reduced energy targets and permitting expansive areas of transparency throughout. The extensive use of glass also reduces the need for electrical lighting during the day.

Figure 2. Atrium layout building plan at Level 3.

BUILDING ENERGY DESIGN

The new headquarters design prioritizes resource conservation in creating a healthy work environment. The building was designed with an array of sustainable features, ultimately reducing energy consumption 25% lower than code requirements. A notable sustainable feature on the campus is a green roof, which reduces the urban heat island effect and creates on-site water conservation through rainwater harvesting. Local and recycled materials are used throughout the building structure, in addition to extensive daylighting of the interior spaces. These features are designed to interact with and complement one another while simultaneously defining the building and landscape aesthetically.

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An under floor air distribution system is used throughout the project for ventilation. In the atrium, where air exchange rates are high due to its entry function, a series of operable transoms are provided above each door to extract heat or provide natural ventilation during mild seasons. The enclosure and mechanical systems at the atrium lobby achieve the high-performance demands required to support the whole-building energy efficiency goals.

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The Atrium facades include the exterior glass curtainwall and cable systems on the south-east and southwest faces of the podium, as illustrated in Figures 2 and 3.

4.1 DESIGN LOADS

The glazing system was designed for +20/-20 PSF wind loads in typical conditions and +20/-30 PSF for corner zones in compliance with ASCE 7-05 Minimum Design Loads for Buildings and Other Structures [1] and the International Building Code, 2006 with City of Seattle Amendments [4]. Seismic design forces were also considered in accordance with ASCE 7-05, 13.3 (ASCE/SEI, 2006).

Additional superimposed loads at the Level 5 roof deck by others at the atrium structure include:

- Green Roof Dead Load $D_{gr} = 47$ PSF
- Office Type 2 Dead Load $D_{of2} = 17$ PSF
- Green Roof Live Load $L_{r,gr} = 25$ PSF
- Office Type 2 Live Load at Level 5 $L_{r,of2} = 80$ PSF

4.2 GLAZING

Typical glass panels are 6'-8" wide x 7'-0" tall, fully tempered insulated units with glass edges set ¾" apart to create a joint filled with sealant to the exterior, foam backer rod infill, and a custom gasket lining the interior. These fully-tempered insulated glazing units have a 1.7" nominal thickness composed of 0.370" SBF30XL outer light, 0.50" argon-filled air space, and 0.80" laminated inner lite composed of two 10mm lites with a 0.06" interlayer (Figure 5, top).

The insulated glass unit (IGU) edge deflection limit is $L/140$, or 0.6" along the 84" height of the typical panel. Using a finite element analysis (FEA) to simulate the composite interaction between the IGU layers and point support conditions at each corner located 5" off center, the critical edge deflection was <0.48" — within the permissible limits (Figure 5, bottom).

Atypical units along the corner and edge conditions were evaluated in a similar fashion to validate the glass units adhere to the stress and deflection criteria. The edge panel proved to be the most stressed glazing panel under design loads due to asymmetrical support conditions: continuous support along one vertical side, and one opposite corner with a relative displacement $\Delta = 1.27"$ forcing the planar rectangle into a warped condition.

4.3 FITTING ATTACHMENT

The cable fitting assembly is a custom attachment designed to transfer loads from the exterior insulated glazing units to a one-way vertical support cable structural element. The cable clamp glass fitting is comprised of four primary components cast out of AISI Type 316 stainless steel: cable clamp back, cable clamp front, fitting armature, and patch plate elements. Additional connection components include neoprene pads, ¼" stainless steel patchplate screws (4 ea.), 1/8" stainless steel pin (2 ea.), 7/8" stainless steel threaded stud (1 ea.) and 5/8" stainless steel cable clamp bolts (2 ea.). The components are diagramed in Figure 6, though connection components are excluded for clarity.
4.4 STRUCTURE

The atrium facade support structure consists of 29 vertical 28mmØ stainless steel cables, each pre-tensioned with 48,000 lbs of initial axial force. The top connection of the vertical member is achieved with an open swaged fitting at the cable’s end, pinned to a gusset plate which cantilevers 4’ outward from the primary W18 box beam structural member at the roof Level 5, 57’-9” above ground level. The preliminary engineering for the top connection gusset plate anchor was performed by the facade contractor; however, the fabrication of the steel tab was performed by the steel contractor in a controlled shop environment prior to arrival at site. Ultimately a survey was performed in-situ to validate that the top pin locations adhered to a field tolerance of ±1/32” of the design location.

As the vertical cable is stretched to the bottom connection it penetrates a metal panel soffit at Level 2, 12’-6” above ground level, where the insulated glazing terminates and a series of portal doors are recessed 10’-7” by the facade contractor; however, the connection gusset plate anchor was performed by the facade contractor in a controlled shop environment prior to arrival at site. Ultimately a survey was performed in-situ to validate that the top pin locations adhered to a field tolerance of ±1/32” of the design location.

The primary building structure. The maximum cable deflection under loading was \( \Delta_m = 8.4’ \) occurring mid-span along the southeast facade. The flexibility of the facade support tension structure requires the boundary structure to accommodate the pre-tensioning process during installation; this is discussed later in further detail.

Though the combined length of the cable and rod vertical member is 61’-6” total, the free-span for the cable member occurs between the top connection and a bracing strut at the soffit Level 2. The free-span behind the glazing is 45’ with deflection criteria of 1/50 permitting maximum cable deflections of 10’-0” under loading. A computer analysis model of the southeast and southwest atrium cable facades was created using the software program SpaceGASS. The previously introduced design loads were applied, after which the software determines the structural and deformational responses of the members, taking in to account the relative stiffness of the primary building structure. The maximum cable deflection under loading was \( \Delta_m = 8.4’ \) occurring mid-span along the southeast facade. The flexibility of the facade support tension structure requires the boundary structure to accommodate the pre-tensioning process during installation; this is discussed later in further detail.

5 THERMAL PERFORMANCE

The typical curtainwall systems for the project included several mockups: visual, performance and blast testing. The atrium facade included a physical mockup only for performance testing. The thermal performance of the point-supported atrium glazing was determined using computer simulation and physical testing in accordance with the National Fenestration Ratings Council (NFRC) standards to obtain the system’s U-values and solar heat gain coefficient (SHGC) to validate their compatibility with target performance values utilized in energy modeling.

5.1 NFRC TESTING

The purpose for implementing NFRC certification requirements on the Seattle Foundation project was to ensure the site-built product met or exceeded target performance values established earlier in the design process by the mechanical engineer. The enclosure’s role in the energy performance was fundamental in supporting the ambitious LEED targets for the project. The NFRC procedures also ensure that the values are calculated using uniform and accurate means.

The facade contractor’s first step in validating the glazing system performance was by performing computer simulations in agreement with the NFRC procedures, using Windows 5.2 and Therm 5.2. Then each product and unique glass type must be tested through an NFRC authorized independent laboratory and their respective performance values loaded directly into the NFRC database. The computer simulations revealed the target performance values were met.

Following the simulation phase, two NFRC physical tests were applied to the atrium facade. They include NFRC 100 Procedure for Determining Fenestration Product U-Factors (2004) and NFRC 200 Procedure for Determining Fenestration Product Solar Heat Gain Coefficients at Normal Incidence (2004). Each of these tests utilizes an 80 in. x 80 in. (2032 mm x 2032 mm) model size for a non-residential site-built glazed wall system. Since the enclosure is a curtainwall system the model must be simulated and tested with two loads, one vertical and one horizontal, as well as intermediate verticals for jamb conditions and intermediate horizontal as well. Since the enclosure is a curtainwall system the model must be simulated and tested with two loads, one vertical and one horizontal, as well as intermediate verticals for jamb conditions and intermediate horizontal as well.

5.2 NFRC RATING

Subsequent to successful testing, an independent inspection agency validates the thermal simulation by issuing a Certificate of Authorization Report (CAR), which is posted directly to the NFRC database. In parallel to a CAR, the independent agency generates a site-built product Label Certificate which identifies the specific product, manufacture, glass type and product ratings (Figure 6). The performance ratings for the atrium point-supported facade include U-values of 0.27 Btu/hr-sqft°F, which exceeds the U-value of 0.34 Btu/hr-sqft°F achieved elsewhere in the project’s aluminum framed curtainwall. The NFRC certificate requires the independent agency to visit the product manufacture and perform an inspection of records demonstrating that the certified product has been produced and implemented in accordance with the thermal simulations and tests.

6 INSTALLATION

The point-supported atrium facade system is backed by a series of 29 vertical cables that rely on an induced pre-tension to provide stability. The tensioning process is very similar to tuning a guitar; however, the scale of the 61’-6” long cables and the large forces make the system extremely sensitive to movements and require specialized equipment to install. The following section outlines the pre-tensioning process, including several of the inherent challenges, and a discussion of how the flexible system accommodates rigorous construction tolerances throughout installation.

6.1 PRE-TENSIONING

The installation of the cable wall commences at the top and bottom anchor conditions. The top anchor of each vertical member consists of a gusset plate cantilevering 4’ outward from the primary steel box beam at the roof (Level 5). The vertical cables are attached at this location by a stainless steel clavus.
condition with a stainless steel pin, releasing the connection for rotation when the cable is subject to lateral load. Each of the cable’s bottom end is attached to a threaded rod near the ground level. This rod penetrates the bottom anchor box, which cantilevers from a welded connection to a steel embed plate within the concrete foundation. On the underside of the bottom anchor box the threaded rod is restrained by a large nut upon a series of stepped plate washers. At this point the cable rests in place under gravity, although the system requires an induced pre-tension to provide stability.

Using the bottom anchor box as a jacking seat, a custom jacking assembly is used to mount two 20-ton hydraulic canisters to the facade (Figure 10, left). These canisters are tied back to a control manifold which supplies the pressure required to expand the canisters, thus elongating the cable. The axial tension in the cable is monitored by a tension meter (Figure 10, right) that is tied back to an insulated glazing unit.

The tendency of the one-way cable to twist under axial loads can result in undesired alignments of connection fittings. On the Foundation’s atrium, the cable twisting had to be mitigated to ensure the exposed cable-to-threaded rod connection exposed above the plaza level was consistently oriented perpendicular to the elevation. Each cable was rotated 180 degrees clockwise prior to installing the pre-tension forces. As the cable gradually received the pre-tension it began to rotate counter-clockwise towards its desired perpendicular final position. It is important to account for the effects of twisting prior to tensioning as the large forces present challenges in rotating the cable or fittings while under loading. Modifications would require a release of the pre-tension and a repeat of the process.

Another issue that arises during the tensioning process relates to the balancing of loads as the boundary structure – in this case the roof steel – deflects and adjusts with the addition of each pre-tensioned cable. This behavior is studied using installation sequence simulations in a structural analysis tool prior to field installation. Each cable is pre-tensioned to a target pre-tension design value. The pre-tensioning of all 29 cables, the system is given a minimum of 100 hours to settle before a second round of tension meter measurements are performed to validate each cable’s pre-tension is at the target 48,000 lbs, or within an acceptable variance of +/- 5%. Once verified, the cables are ready to receive the clamp fittings and ultimately the insulated glazing units.

6.2 TOLERANCES

The atrium facade’s major challenges was the tolerance requirements for the glass and point-supported fittings. The facade had to meet a final face of glass location within ±1/8” tolerance in any direction. However, the system is designed to accommodate primary structural tolerances of 1” in any direction for steel and ¾” in any direction for concrete. The cable wall used precision surveying prior to installation, as well as built-in accommodation points at the bottom connection and with the patch-plate fitting assembly. The bottom anchor box included an oversized pipe sleeve through the HS1 to allow the threaded rods to penetrate and be restrained to the underside. The oversized hole provided more than the 1.50” tolerance required in the side-to-side and in-out directions. Each clamped cable fitting with patch plate attachments for the glass provided adjusted tolerance in every direction. Vertically, the clamps could be slid up and down the cable and re-clamped. The patch plates attach to the spider armatures with a stainless steel pin at a slotted connection that also permits movement under a seismic event. The secondary patch plates are designed to accommodate ±1/8” in any direction and ±5% in any direction.

REFERENCES