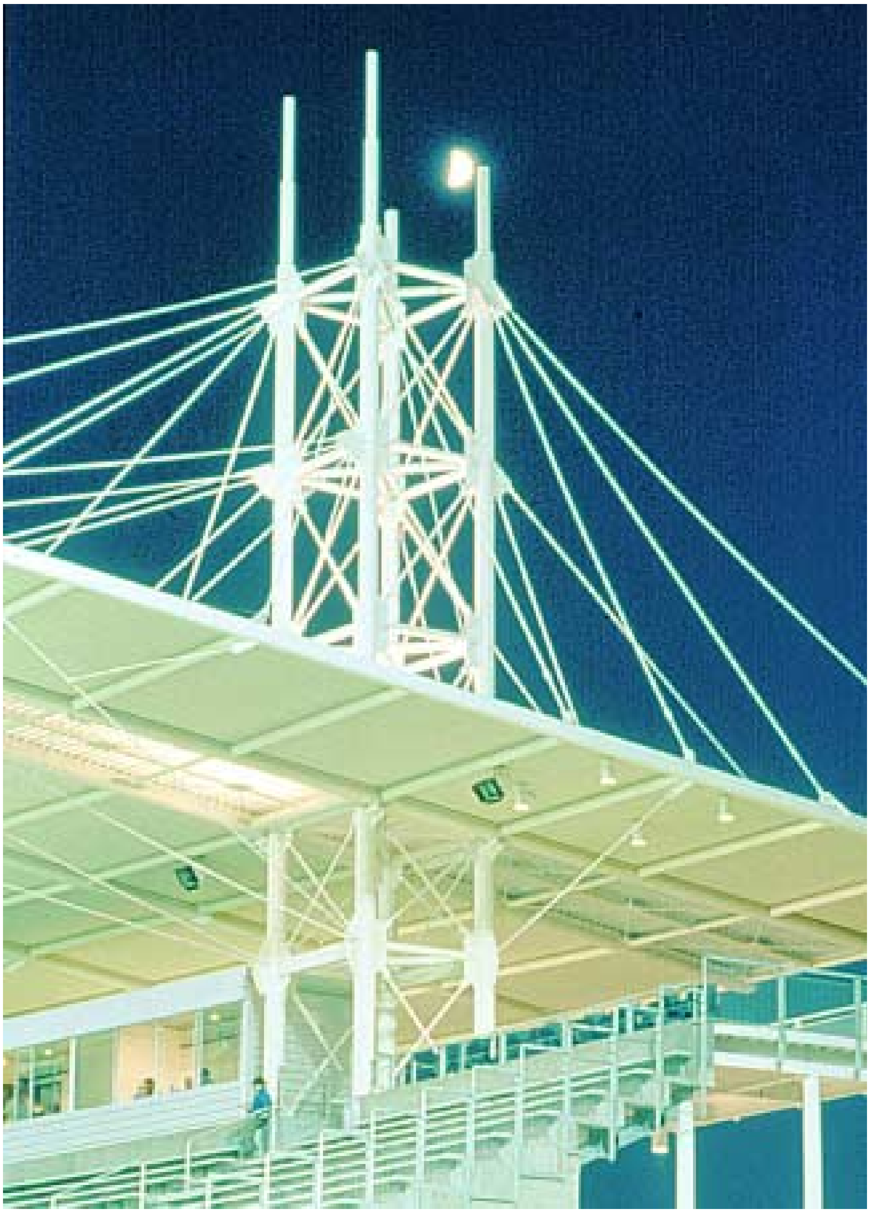
Engineering Awards of Excellence

National Winner

Hillsboro Stadium

Hillsboro, Oregon



The success of the Hillsboro Stadium project was based on the design team's ability to be creative in its response to the owner's (The Hillsboro Parks and Recreation Department) and architect's (GBD Architects) requirements.

The owner, due to cost overruns and a long construction schedule, abandoned a previous design by another team. KPFF, along with the other team members, came up with a design that met both the budget for the project and the design and construction schedule required by the owner. The Hillsboro Parks and Recreation Department received its funding for the stadium from a combination of private and public donations and a recently approved bond measure. When the overall 10-month schedule was broken down into tasks, KPFF was left with 30 days to complete the design and issue bid documents for the stadium, a significant engineering achievement.

KPFF provided structural engineering design and construction services for the Hillsboro Stadium in Hillsboro, OR. The project includes a 4,000-seat bleacher stadium with a 25,000-sq. ft. roof, suspended from four steel towers located along the backside of the stadium. The roof partially covers the bleachers and three enclosed private press boxes that

> **Jurors' Comments:**
> Designed and built in 10 months, this stadium is a perfect blend of simple but elegant design, economy and speed through pre-fabrication. The canopied roof structure stands out like a jewel.

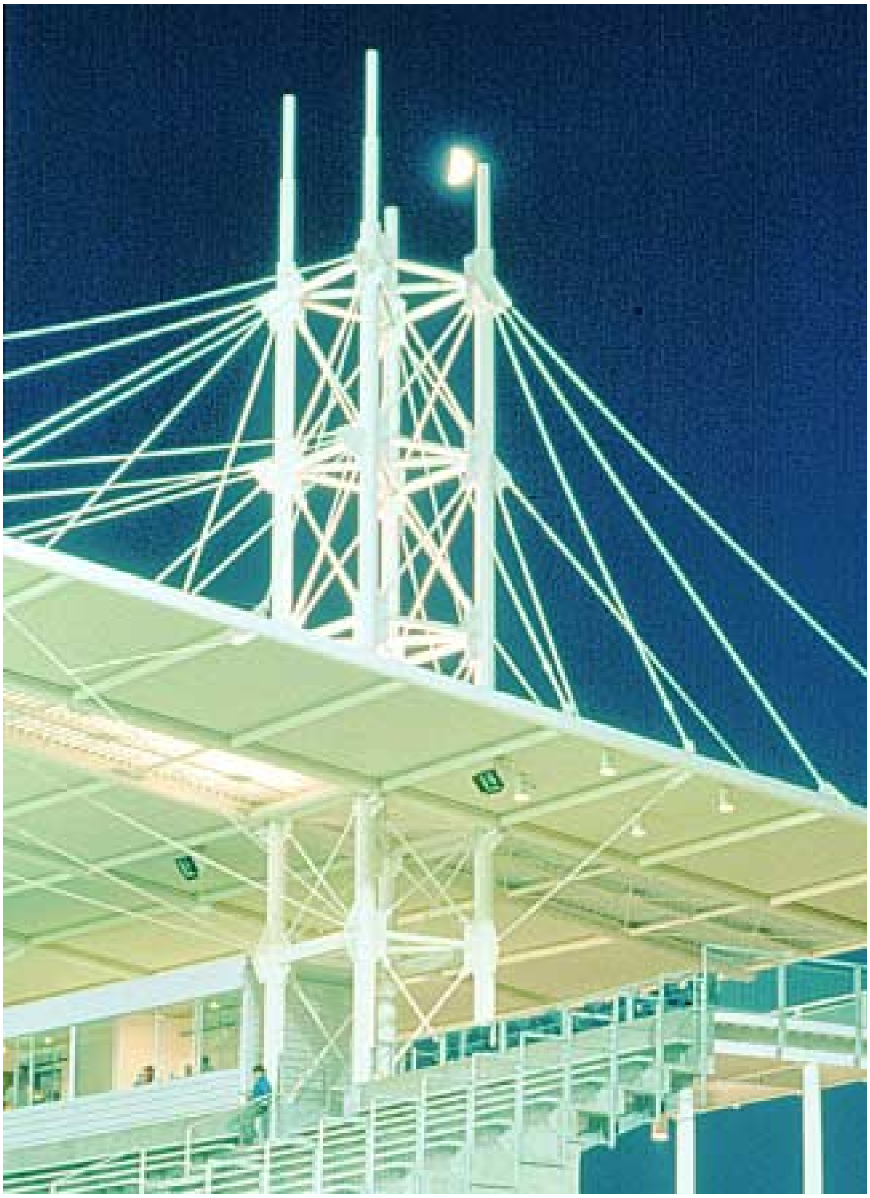
overlook the multipurpose Astroturf field, which supports baseball, football, and soccer. Six additional grass softball and baseball fields surround the stadium.

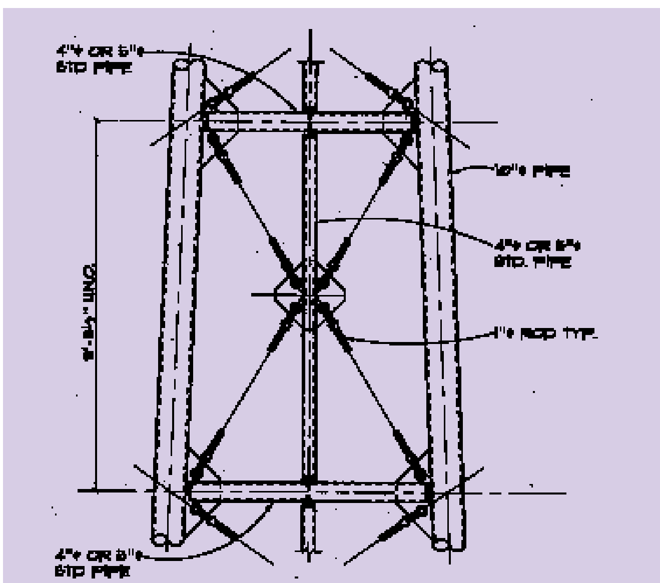
The seating was constructed using 25' long by 3' 9" wide precast concrete planks supported by structural steel beams and columns. Below the bleachers are restrooms, concession booths, team locker rooms, and ground maintenance and storage facilities. The project was designed and built for the City of Hillsboro Parks and Recreation Department for use by local high schools, youth, and adult sports organizations. Completed in August of 1999, the construction cost for the stadium was $7,400,000. The stadium included 400 tons of structural steel.

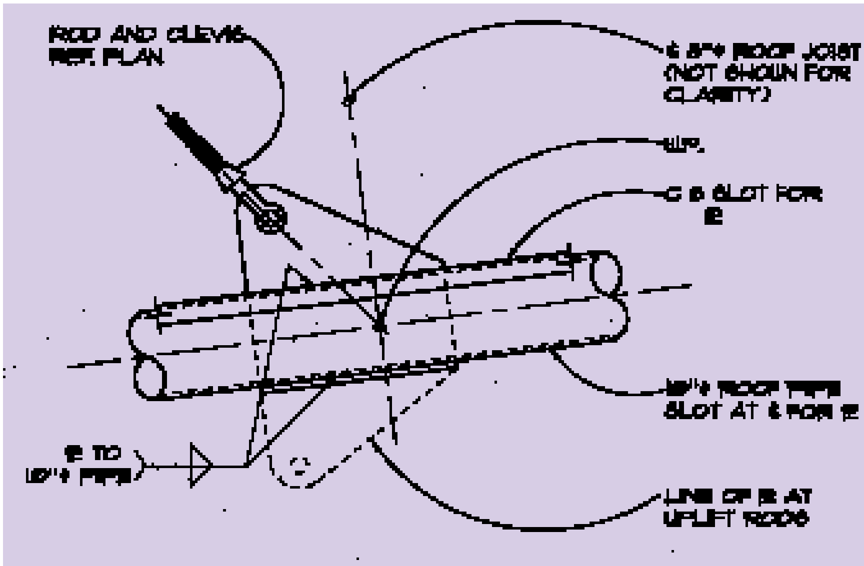
In order to meet the owner's demanding cost and budget constraints, the design team created a simple, structurally sound, and aesthetically pleasing design using prefabricated roof sections that could be installed while the supporting structure was built.

Concurrent Construction

The key to the project's success was that different sections of the stadium could be designed, built, and installed concurrently. The







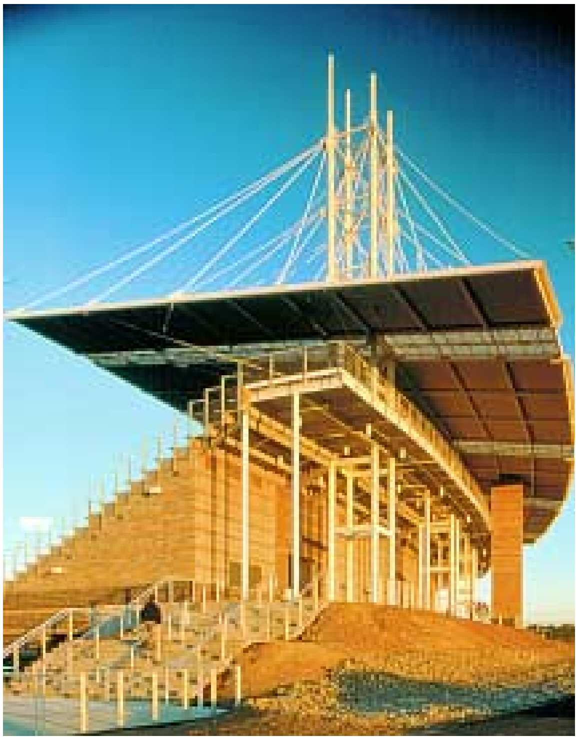
engineers designed a canopied-roof system that was completely independent of the stadium seating section. While the stadium seating area was being constructed, the roof was also being constructed in an adjacent field. Once the seating area was complete, the roof system was lifted into place and attached to 80 suspension rods and 16 uplift rods suspended from four steel towers.

The four steel roof towers were also prefabricated in two sections and lifted into place. The lower sections of the towers were fabricated and placed prior to construction of the seating area. While the seating area was being installed, the upper roof tower sections were being constructed and were lifted into place prior to completion of the roof panels. The roof panels were constructed in three 53' by 100' sections, which were set between the towers, and two 25' by 100' sections, which were placed at the ends of the roof. Two independent cranes lifted the roof panels. It took approximately eight hours to lift and secure each panel. The framing in the wedge-shaped skylights was installed after the main roof panels were installed.

The suspension rods, which splay out from the top of the towers down to the roof structure, carry all of the gravity load of the roof system. The roof is offset from the roof towers, which creates an inherent eccentricity. The support towers must withstand constant overturning forces caused by the structures' eccentricity, wind, and seismic loads. Additionally, the support towers were designed to accommodate the unbalanced loads that occurred during construction when an adjacent roof panel had not yet been lifted into place. This eliminated the need for shoring and provided the steel erector with a wide range of erection sequences.

The seating raker beams attach to the roof towers, approximately 43' above the field at the press box floor, and provide stability to the roof towers. The steel raker beams act as a compression strut to transfer the loads down to the concourse level, which is 15' above the field level. The concourse level is rigidly anchored to a deep grade beam at the back of the stadium.

The owner was pleased with the aesthetic quality of the system and the design team's ability to create a structural system that could be designed and constructed within the required 10-month period while remaining within the owner's budget. The design team's hard work and innovative use of structural steel made this project a success for everyone involved, including the owner and the members of the community, who will have full use of the facility.



Hillsboro Stadium, Hillsboro, OR

Owner: The Hillsboro Parks and Recreation Department

Architect: GBD Architects, Portland, OR

Structural Engineer: KPFF, Portland, OR

Fabricator: Fought & Co., Tigard, OR *(AISC member)*

Detailer: Baresel Corp. *(AISC & NISD members)*

General Contractor: Hoffman Construction Co., Portland

Engineering Awards of Excellence

National Winner

Pacific Place

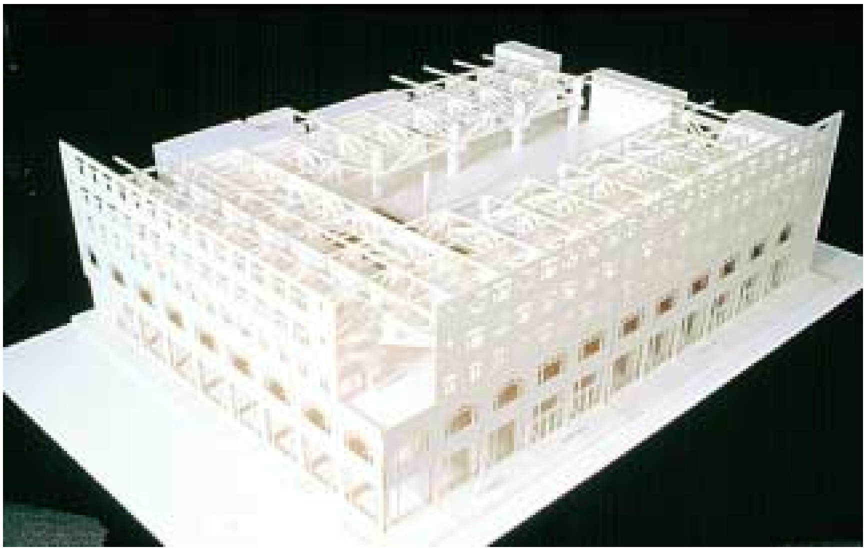
San Francisco, California

The Pacific Place project is a major reconstruction and seismic upgrade of a Category 1 historic building. When built in 1908, it was the largest concrete office building in the country. The structure is a ten story non-ductile concrete frame, 192’ by 144’ in plan. To convert the existing floor plan, with its 16’ by 16’ column grid, to “prime” retail space, the developer proposed a bold scheme to remove most of the columns and open up the floor plan. This led to a dramatic and difficult project in which the lower four stories were completely demolished and three floors were reconstructed in their place. This work occurred while the upper five stories remained. Of the original 86 interior columns, 74 were removed (86%), while 12 were strengthened and only 15 columns were added.

The greatest challenge of the project was to devise a structure within the existing structure to transfer loads from the existing upper five floors to the new lower floors, without shoring. This integrated approach proved cost effective. As such, the success of this job depended on the engineer dictating the construction sequence. The design used preloading of the truss network to eliminate deflections at load transfer and protect the existing brittle structure.

Construction Sequence

After the construction of a new foundation system of drilled piers, the contractor erected new columns up through the existing floors and strengthened the existing columns that remained. New floors were then built between the existing framing. Below the 5th floor, each column was sandwiched between two new trusses. Each truss is connected to half of a steel jacket, so that with the trusses in place, a complete steel wrap surrounds the column. Once the contractor placed the new framing within the original framing, trusses were pre-loaded by jacking them against the columns they would carry. When the contractor had the truss network completely stressed to carry 100% of the supported load, the trusses were locked off. At this point, the original framing was demolished from the 5th floor down and the reconstruction was completed.



Seismic Upgrade

The seismic upgrade portion of the project consists of concrete shearwalls mixed with steel braced frames. Steven Tipping + Associates performed a complete pushover analysis to do the capacity design. Many collapse mechanisms were studied using combinations of upper and lower bound values for material and soil strengths under multiple loading patterns to cover the range of failure modes and produce good ductile detailing. To improve performance by effectively increasing the ductility of the braced frames, inexpensive friction dampers were added which utilize sandwiched brass shims, pre-tensioned bolts, and slotted holes.

This project is exceptional in its scope and technical difficulty. In its finished state, people can walk under the exposed network of supporting trusses, see suspended ends of removed columns, and understand how the structure works. It is an outstanding example of exposed structure in a dramatic commercial space and a credit to the work of engineers and builders.

Pacific Place, San Francisco

Owner: Pacific Resources PCX Development, Inc., San Francisco, CA

Architect: Gensler, San Francisco, CA

Structural Engineer: Stephen Tipping + Associates, Berkeley, CA

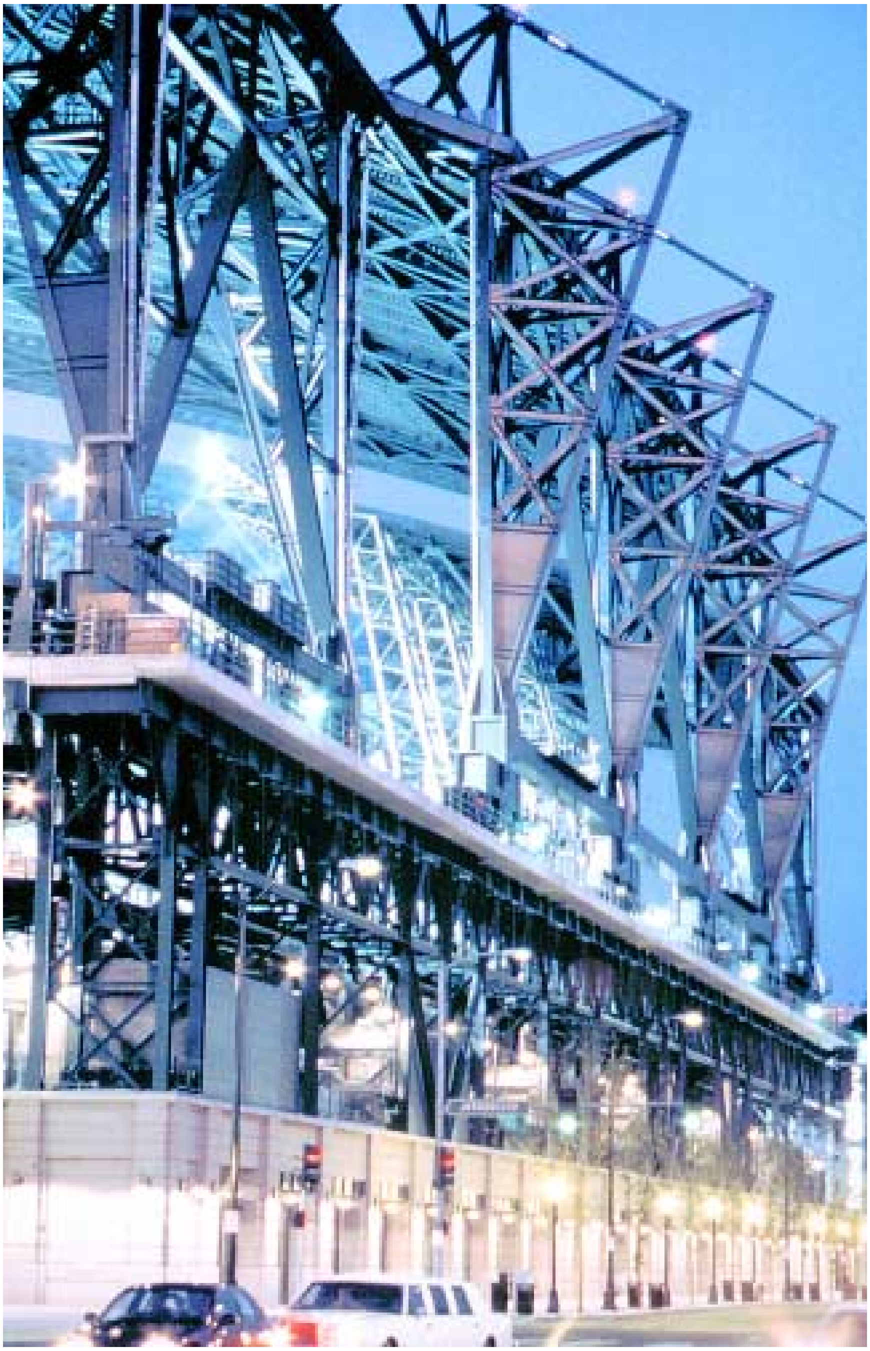
Steel Fabricator: W & W Steel Co., Oklahoma City, OK *(AISC member)*

General Contractor: Plant Construction, San Francisco, CA

Engineering Awards of Excellence
National Winner

Safeco Field

Seattle, Washington



In 1995, Seattle's professional baseball team, the Mariners, decided they wanted a new stadium. Across the country, great baseball venues were being created, echoing the early days of old-style stadiums, fresh grass fields, and the great outdoors. After 21 years of playing in the fully enclosed Kingdome, the Mariners, too, wanted out in the sun, both for the joy of playing outside and the financial boost it would bring the team.

But Seattle's rainy climate dictated that the stadium be equipped with an "umbrella" to shield fans on days of inclement weather. And, thus, the demand was made: Build us a new stadium, open to the sky, with real grass, but make sure we can cover the field and the fans when it rains. Plus, do it by opening day 1999. With those ground rules, the design team set to work.

The result is Safeco Field, a 47,000 seat, state-of-the-art, retractable roof ballpark. This one-of-a-kind project offers a landmark public amenity that will keep major league baseball in the region for years to come. It provides good family entertainment, while stimulating economic growth and redevelopment in the area.

Proactive management and innovative design solutions were required to meet the aggressive

project schedule and design challenges. The retractable roof was designed for speedy erection and to minimize the impact on the construction of the seating bowl. The close proximity to the Seattle Fault required special seismic considerations, such as the use of an innovative viscous damping system in the roof that reduces the seismic forces by 50%.

The exposed steel structure was designed to be functional as well as aesthetically interesting. The complex dynamic interaction between the three roof panels and the supporting runway required the use of very sophisticated leading-edge analytical techniques. Large, three-dimensional, nonlinear, time history analytical models were used to simulate different earthquakes and develop the criteria for designing the damping system.

The roof has over 12,800 individual pieces, weighing a total of 10,800 tons. It covers 8.8 acres and is supported by eight 655' long tri-chord trusses. The roof rests on eight 90' tall steel lattice legs. The trusses are pinned at one end to allow for lateral deflections due to temperature expansion and snow loads without imposing large stress in the structure. The legs are supported

on large travel trucks, which move along two elevated runway structures on the north and south sides of the stadium. Through this system, the stadium roof moves at the rate of 1' per second, taking 10 minutes to fully open or close in moderate winds up to 20 mph.

The stadium was designed in an amazing 9 months and built in just 27 months, 16 months less than a normal design and construction schedule. The project is definitely a home run experience, revitalizing the team, the fans, and the city.

Satisfying the Building Program

The demands of the building program, as detailed in the contract between the Washington State Public Facilities District (appointed by Governor Gary Locke to oversee construction of the stadium) and the design team, were few and straightforward, yet also incredibly complex and challenging:

- Build a new retractable roof, world-class major league baseball stadium and entertainment complex
- Accommodate 47,000 fans, including 70 to 75 standard suites and 5 to 7 party suites
- Include administrative offices, a stadium club, restaurant(s), state-of-the-art clubhouses, and parking facilities
- Incorporate the retractable roof as an "integral part of the design"
- Construct the roof to expose as many fans as possible to the outdoors when it is open
- Provide a natural grass baseball field
- Locate the stadium near the Kingdome in Seattle, Washington, on a site constricted on three sides by busy streets and the Kingdome on the fourth.
- Provide an architectural connection to the adjacent Pioneer Square historical district
- Complete the stadium in time for opening day 1999

Jurors' Comments:

A one-of-a-kind project taking a moveable roof stadium to a new level in a seismic design. Designed in just nine months and constructed in just 27 months, the engineers met a long series of complex challenges.

Application of New or Innovative Technologies

The use of steel was the key to the stadium's success. Apart from the precast seating bowl, virtually all the project elements incorporated steel. Below is an explanation of some of the more outstanding and innovative ideas and technologies applied. Several new and innovative applications were incorporated into the roof design:

First-Ever Fully Retractable Roof Utilizing Linear Tracking Movement With Three Independent Roof Panels

Each of Safeco Field's three roof panels is completely independent, as opposed to the interdependent panels of the ballpark in Phoenix, where the edge of each panel is supported on the adjacent panel. By making the panels independent, less steel was needed, and roof construction could be completed over the railroad tracks without interfering with construction of the seating bowl.

The linear tracking and independent panel design of Safeco Field allowed the roof to be fully stacked and provided a simpler method of dealing with temperature expansion and seismic displacement. In the retracted position, the three panels are stacked, which allows the roof to be completely retracted off the stadium and stored over the adjacent railroad tracks under a long-term air-rights agreement with Burlington Northern. By completely retracting off the field, fans can enjoy a totally open ballpark, and not just a "peek-a-boo" view to the sky.

Only Retractable Roof Ballpark In UBC Seismic Zones 3 or 4

Not only is the stadium located in Seismic Zone 3, it is built near the Seattle fault! The use of viscous dampers mounted on the roof panels play an important role in dissipating seismic energy and reducing overall lateral forces. This provided a very economical design and saved over $5,000,000 in construction costs.

The original roof design consisted of five panels. In an effort to reduce the overall cost of the stadium, the original restrictive stacking requirements were relaxed, which allowed the number of roof panels to be reduced from five to three. A 70' curved "brow" cantilevers off the retractable roof and fills the gap between the roof truss and the sun canopy.

The final solution also skewed the roof 8 degrees, to more closely align the panels with the field. Both of these ideas resulted in complete field coverage while eliminating the expense of the two additional roof panels, reducing the overall area by 30%, and cutting 100' off the length of each runway structure. The redesign reduced the original $100 million roof estimate by nearly $30 million.

Most structures don't move and can be analyzed using conventional tools with approximately 100 load cases. The moving roof of Safeco Field presented a totally different challenge. As the roof moves along the runways, the stiffness and distribution of the

mass of the structure constantly changes. Essentially, the stadium becomes many different structures, depending on the roof location. Gravity, wind, and seismic loads were evaluated at incremental stages along the runway so account for all the possible loading conditions. An analysis was performed using 1,500 different load combinations.

In an application never before attempted, variable-depth, variable-width tri-chord trusses were selected to support the stadium's retractable roof. The selection of the tri-chord trusses was arrived at after considering a multitude of different structural, architectural, and constructability criteria. The sleek upturned tri-chord trusses are one of the primary defining architectural features of the ballpark. The very stable tri-chord configuration allows the trusses to be erected on a stationary work platform, then rolled aside to make way for the next truss. The tri-chord truss is the most efficient way to span long distances when using an upturned truss.

"Not only were they more stable, they were more beautiful," said NBBJ principal and design team member Richard L. Zieve.

Trusses Enhance

Construction

Once constructed, the dramatic tri-chord trusses are self-supporting. By taking advantage of this feature, a greatly simplified and shortened construction sequence was determined. A single erection platform was built directly outside the stadium footprint towards the railroad tracks. Once each truss was complete, it was released to be self-supporting, then rolled along the runway trestle to be temporarily stored in the "air-rights" area over the railroad tracks. This allowed construction of the next truss to proceed on the same erection platform.

After all the lower trusses (for the end panels) were erected, the platform was extended 50' to continue with erection of the taller trusses. By removing the roof erection from the critical path for the stadium, construction of the stadium bowl could proceed unimpeded. Additionally, this solution minimized disruption to the West Coast's main north/south Burlington Northern route.

As each truss was built, it was temporarily supported on the erection platform. A jacking system on the platform allowed each truss to "drop" into its self-sup-

porting position. The trusses also changed position as the secondary framing and roof panels were added. A sophisticated stability check was performed on all the trusses to ensure they would span in both their temporary and final conditions. The check predicted that roof movements would be 18" vertical at center and 9" horizontally at the ends. Actual deflection was within an amazing 3/8" of that predicted!

The tri-chord truss designs involved incredibly complex connections and geometry. To facilitate construction, the entire analysis database was provided to the builders, who incorporated the information to make their process more effective.

New and Innovative Use of Viscous Dampers

Safeco Field incorporates dampers in a first-ever use of its type. The dampers are also the largest viscous dampers ever used in a building application. On the south side of the stadium, the roof secures to its lattice steel legs by rigid connections. On the north side, 18-inch-diameter, 22-foot-long viscous dampers laterally secure the roof to the legs. Like shock absorbers on a car, the 800-kip dampers absorb earthquake and windstorm energy and dissipate forces from a potential seismic event.

During the design process, the stadium was subject to 30 major earthquakes…not real earthquakes, but computer simulations. The dampers allow the roof to deflect up to 6" through a hinge located between each horizontal truss and its leg. In essence, this makes the structure transparent to temperature and snow horizontal thrust force.

A new 3-D modeling program was used to evaluate the dampers and predict how they would perform through 12 different time histories (with 10,000 elements). The program digitized ground motion to 1/50th of a second. Use of the dampers cut the seismic forces in half and reduced the size and stiffness of the runways by 50%. Although the dampers cost $750,000 (including testing), they cut $5 million from the cost of the stadium.

Additionally, a computerized monitoring system utilizing 50 accelerometers was put in place to verify damper performance in the event of an earthquake or high-wind event. The monitors will capture data for review of displacement, and determine if the Mariners can play ball immediately after a seismic event.

Wind Won't Blow The Game

One of the most critical design requirements for the Safeco Field roof was providing wind resistance during storms. In many ways, the roof is more like a long-span bridge than a building. To fully understand the effect of storms on the structure, a series of tests were conducted on detailed scale models at a wind tunnel in Toronto, Canada. The tests simulated storms coming from all directions and used probability theory to predict the appropriate levels of stress in the structure.

When in the extended or retracted positions, the roof sections have "lock-down" devices that tie them to the support below, to provide additional wind resistance. If there is a forecast of storm winds, the roof will not be moved between the lock-down positions.

Lattice Steel Legs Function as Moving Support System

Supporting the roof on steel "legs" allowed lowering of the north runway and also further reduced construction costs, since these support legs move with the roof, rather than support it as it moves. To briefly explain, as moving weight travels across a supporting structure, each and every piece beneath it much be designed to support the weight. For example, if there were 40 fixed vertical supports, all 40 would have to be able to carry the full load of the roof as it passes overhead. However, since the legs that support the roof actually travel with the moving weight, only the 16 legs had to be designed to carry the roof weight. This unique concept of moving support drastically reduced the construction cost.

Because of the seismic requirements, plan, and size of building, the stadium is actually designed as seven separate structures, joined only with seismic expansion joints. This design permitted simultaneous field-level and upper deck construction, which pared the 18-month calendar of civil, foundations, and rough electrical work to 10 months.

To complicate matters even further, a 15' layer of liquifiable soils meant that the structure had to be designed so that it could "float" in the event of an earthquake. The structure was therefore built on concrete-filled pipe column piles driven to a depth of 60 to 100'.

The runway structures also required complex analysis, to appropriately design for moving wheel loads of 230 kips each. It was necessary to design the runways in one single piece—without any joints—so that splices would not interfere with trolley travel.

To accomplish this, the lateral load was concentrated in the center of the runway structure in the longitudinal direction, and the runways were cut loose from the stadium bowl on either end. Designing the runway structures to be structurally independent of the bowl was also key to facilitating roof construction concurrent with the bowl. Additional analysis had to address the fact that the behavior of the runway structure varied, depending on the location of the roof. The structure is stiffer over the bowl, and not as stiff as it extends away.

The incredibly complex nature of the geometries and sequencing required that the stadium be detailed and built in four stages. The stages were determined through a phased analysis, which predicted where the structure would be at the time the next stage was built. The four stages used were as follows:

- Construction of the tri-chord roof trusses, shored on the staging platform
- Geometry after the trusses were released from the platform and standing alone
- Geometry after the secondary roof framing was installed
- Geometry when the roof "eyebrow" was added

The structure was designed to the 1997 Uniform Building Code before the code was released. By sorting through the various proposed code additions and ascertaining the intent of the new code, it was possible to design the stadium using the latest proposed seismic provisions. This provides the safest, state-of-the-art structure: a stadium built today that meets the codes of tomorrow.

Safeco Field

Seattle, Washington

Owner: Public Facilities District

Architect: NBBJ, Seattle, WA

Structural Engineer:Stephen Tipping + Associates, Berkeley, CA

Steel Fabricator: Fought & Co., Tigard, OR, Herrick Corp., Pleasanton, CA *(AISC members)*

Erector: Herrick Corp., Pleasanton, CA *(AISC member)*

Detailer: DOWCO, Burnaby, BC, CANADA *(AISC & NISD members)*

General Contractor: Huber, Hunt, Nichols/Kiewit, AJV (CM/CG), Seattle, WA

Engineering Awards of Excellence

National Winner

U.S. Coast Guard Hangar

Opa-Locka, Florida

The United States Coast Guard, reflecting increased responsibilities in Florida and the Caribbean basin, selected Air Station Miami to become a Mega Base for USCG Aviation activities. These activities run 24 hours per day 365 days a year and include Search and Rescue operations, Law Enforcement, Drug Interdiction, and National Emergencies.

A program was devised to support this unique mission. The program included new and retrofitted Aviation Maintenance and Operations, new Fuel Farm, new and expanded Airfield Facilities and new Administration Facilities. The planning and design contract was awarded to O'Kon and Company. The most spectacular part of the program is the 165,000 sq. ft. Aviation Maintenance and Flight Operations Center located adjacent to the airfield. This facility is the center of an efficient emergency operation that results in successful missions for the U.S. Coast Guard.

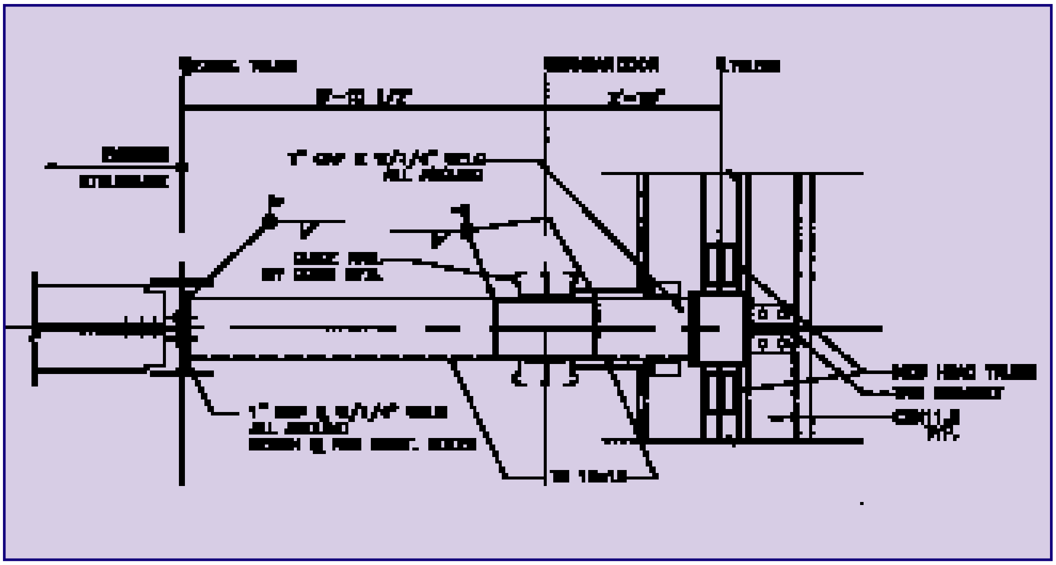
HANGAR DESIGN CHALLENGES

The salient aspect of the new facility is a 26,000 sq. ft. nine position hangar for the HH-65 Dolphin helicopter. The facility, which boasts a 260' clear span, is adjacent to the flight line and at an intersection of two active taxiways. The design challenge of this long span facility was not only to develop a hangar with proper vertical clearances for the helicopter and full coverage overhead crane, but also to create a structure that would develop a low profile roofline. The hangar is located directly in the sight line of the control tower, and the FAA decreed that the hangar envelope must be below the sight line.

Creating a hangar envelope that was lower than the control tower sight lines while also providing proper clearances for interior functions resulted in a solution that permitted only a total of 10' of depth for the structure. Also required was the articulation of the structure to permit clear sight lines. This thin structure must withstand 150-mph hurricane winds and 30 psf live loads.

Jurors' Comments:

This 260' span hangar had to meet very demanding requirements for wind loads imposed by the FAA. It also had to satisfy the owner's need for a minimum door height. The use of a pair of articulated, triangular vertical bents and 65 ksi steel limited the structure depth to 10'. The idea of creating an exoskeleton around the hangar envelope eliminated any interior obstructions.



The O'Kon Engineering team used three dimensional computer models to develop a low profile but highly resistant structure. The resulting solution was a pair of articulated, triangular, vertical bents/wind resistant frames featuring circular tube members for the lower chord. This unique solution created a structural exoskeleton around the hangar envelope.

The compactness of the structure required the use of 65-ksi structural steel to reduce the member sizes by making use of the triaxial stiffness of the long span, triangular, truss/bent system. Creativity was used in the selection of upward-acting structural fabric hangar doors to reduce space; however, these doors required special structural details to ensure proper installation. Creativity was further utilized to achieve the owner's requirement of eliminating situations that could damage the delicate rotor blades of the helicopters (i.e. avoiding interior structural bracing). The solution was to create an exoskeleton, place the bents and horizontal lateral force resisting structures on the exterior of the hangar, and place the smooth surface of concrete block walls on the interior. This exoskeleton required unique detailing for design continuity, shipping and erection.

Details were developed that were contractor-friendly. The exoskeleton was designed to be primarily shop-fabricated with a minimum of field fabrication.

UNIQUE FEATURES AND TECHNICAL VALUE

The U.S. Coast Guard commissioned O'Kon and Company to design a state-of-the-art maintenance and operations Mega Base for emergency and life saving operations for third millennium aircraft. The O'Kon team responded with design innovations which included unique structural systems to resist 150 mph winds and 120 psf uplift; complex, government-specified environmental systems; and a low profile structural exoskeleton, which produced significant cost savings while achieving maximum structural resistance as well as satisfying FAA and Coast Guard requirements.

The techniques developed on this unique project have been disseminated to the engineering profession via conferences with the Coast Guard, the U. S. Air Force, and the U.S. Navy, as well as engineering seminars presented by O'Kon and Company in the U.S. and abroad.

The use of three dimensional models to resist unique loadings, the use of high strength steel, and the flexibility of long span steel structures enhanced this creative structural design.

COMPLEXITY OF DESIGN

The design, construction, and operation of a low profile, articulated exoskeleton aviation maintenance facility is one of the most complex of all engineered facilities. The maintenance of strategic aircraft that are on 24 hour per day standby presents a set of unique criteria that is complicated by the threat of hurricanes.

The helicopters must be serviced quickly and efficiently while maintaining the life safety of USCG personnel. Therefore, the hangar has a full coverage crane and full protection devices to protect personnel.

The hangar is protected by a sophisticated foam fire protection system featuring specialized fire detection systems and toxic effluent collection system. All equipment must be explosion resistant, and hydrocarbon exhaust systems

are located through the facility. To enhance flexibility and reduce space, upward acting fabric hangar doors were used requiring special structural details.

SATISFYING THE OWNER'S PROGRAM

The project exceeds the U.S. Coast Guard needs and requirements. The facility is the pride of Air Station Miami, and has gained attention nationally due to its functional capabilities, aesthetic appeal, and creative structure.

The unique exoskeleton structure and its color present a signature structure for the Coast Guard Mega Base. The all-white interior paint of the structure and white floor coating have produced what the U.S. Coast Guard terms "its prototype hangar for the third millennium."

U.S. Coast Guard Hangar, Opa-Locka, FL

Owner: United States Coast Guard

Architect & Structural Engineer: O'Kon & Company, Inc., Atlanta

Steel Fabricator: Industrial Steel, Inc., Mims, FL *(AISC member)*

Erector: Industrial Steel, Inc., Mims, FL *(AISC member)*

Detailer: Structural Technics, Inc., Miami *(AISC & NISD members)*

General Contractor: MCM Engineering and Contractors, Inc., Miami

Engineering Awards of Excellence

Merit Winner

Carmel High School

Carmel, Indiana

The Carmel High School basketball arena was originally constructed in the 1950s, and the superstructure consisted of wood bowstring trusses spanning 151' over a bowl-type arena with a seating capacity of 4,000. In recent years the trusses had suffered significant distress, and conventional repairs had been made, such as the installation of tension rods along the bottom chord to reduce the tension in the original chord. Several engineering consultants had performed analyses of the original roof framing system, and all agreed that the long-term viability of the structure was in question.

The objectives for the owner's/architect's program were as follows:

- Replace a deteriorating wood bowstring truss gymnasium roof structure with a durable steel-framed system.
- Allow a basketball season to proceed undisrupted (Carmel High School typically hosts regional competitions in its 4,000-seat arena); schedule construction over two summers, allowing basketball to be played between construction seasons.
- Maintain an enclosed and dry structure; rainfall and moisture infiltration would be detrimental to the significant portion of the structure that was to be retained.

Decision to Replace

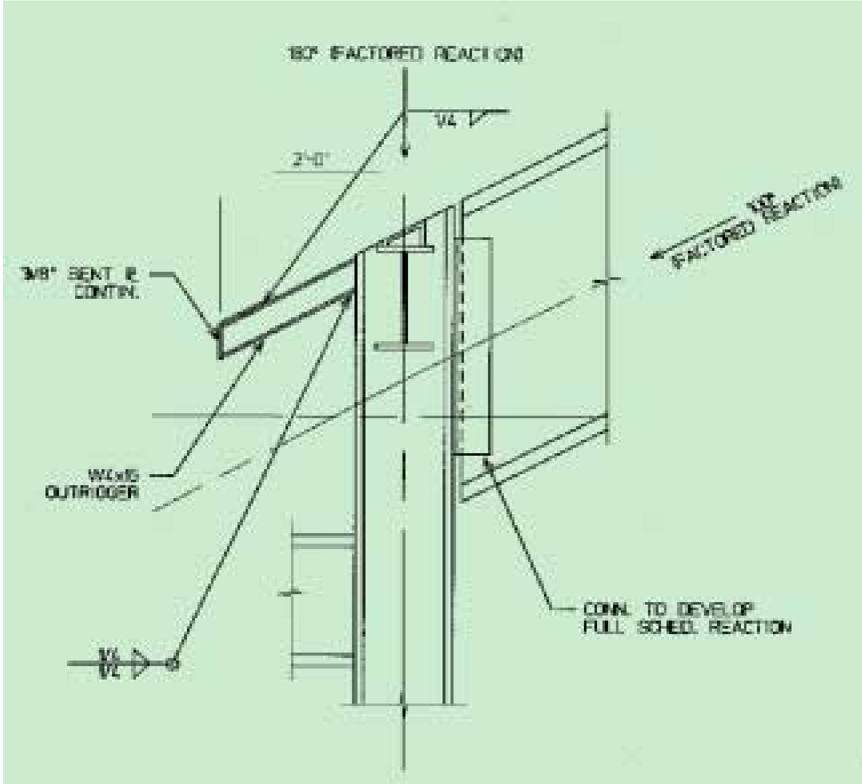
The decision to replace the roof was accelerated by the fact that additions planned for both sides of the building would imminently constrict access to the arena. Furthermore, it was critical to keep the building reasonably dry and enclosed so as not to "lose" a basketball season during construction.

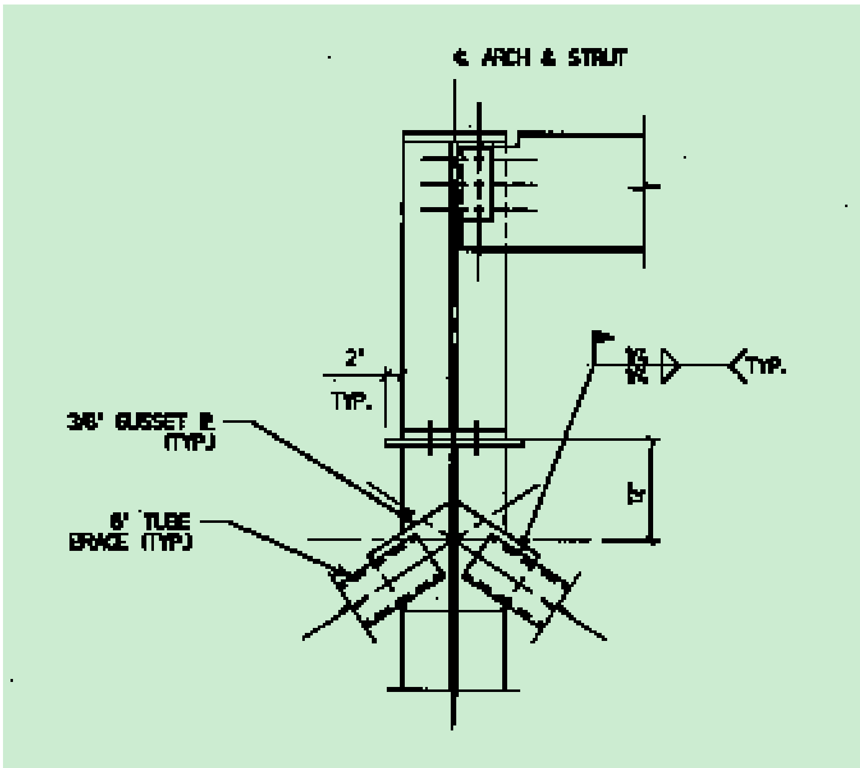
Once the decision was made to replace the existing roof framing system, it was quickly determined that a steel framing system was the appropriate solution. A curved roof form similar to the existing bowstring trusses was the most desirable, from aesthetic and feasibility standpoints. A tied arch system was developed that achieved all of the program objectives.

First Construction Season

A curved W36x170 was designed to support a new roof, 10' above the existing roof. These members were supported on temporary columns located near the first row of seating and, at their ends, by permanent columns located outside of the existing building perimeter. The resulting 176' span covered an enlarged area around the top of the seating bowl, providing improved entry access and wheelchair seating.

The temporary columns were located so that the curved roof structure could be placed over the existing roof and support the arched beam, while not interfering with the use of the basketball court for the following season. These column locations then had to coincide with the position of the verticals in the final tied arch system that was to be completed during the second summer. The temporary columns were supported on new footings and placed through small openings in the existing roof that were sealed





after installation of the columns. The seating areas that were removed to install the footings were repaired, temporary protection of the floor was removed, and basketball proceeded throughout next season; the temporary columns were the only obvious change inside the facility.

Second Construction Season

During the second summer, the original roof and bowstring trusses were removed. The tie members were erected from the gym floor, and the tied arch system was completed. The portion of the temporary column below the tie member was then removed. A bolted cap/base plate was provided, in the temporary column at the bottom of the tie, to allow for easy removal of this member and eliminate the need for any additional field welding or repairs at one of the most critical points in the system. The column bases were cut with a conventional torch and removed. The actual deflections that occurred, when the load transferred to the final structural system, matched the calculated deflections.

In the completed structure, the tied arches are spaced at 30' on center, with W14 purlins 7' on center spanning between the arches. Acoustical metal roof deck of 1½" wide-rib was used to span between the purlins. Horizontal x-bracing in the plane of the roof and vertical x-bracing at each corner provide lateral resistance to wind pressures. All of the roof-framing members, bracing, decking, and roofing were installed during the first summer to ensure stability. Following installation of the final tied arch members, x-type bridging was provided to stabilize the tension chord. Sag rods were utilized to prevent deflection of the horizontal bottom chord, an 84' long W10x68. Following completion of the structure, a new gym floor and basketball standards were installed, and the seating was completely refurbished.

Project Completion

Three-dimensional models were used to analyze the structure to ensure stability and integrity under several configurations. Coordination with the structural steel detailer, fabricator, and erector resulted in a structural system that was fabricated and erected with no significant problems or delays.

The increased volume of the building, which was completed in the Fall of 1997, and the slenderness of the structural system provide a dramatic facility for Indiana's #1 high school sport.

Carmel High School, Carmel, IN

Owner: Carmel School Corporation

Architect: OWP&P Architects, Chicago, IL

Structural Engineer: OWP&P Architects, Chicago, IL

Fabricator: Geiger & Peters, Inc., Indianapolis, IN *(AISC member)*

Detailer: Geiger & Peters Inc., Indianapolis, IN *(AISC member)*

General Contractor: Huber Hunt & Nichols, Indianapolis, IN

Engineering Awards of Excellence

Merit Winner

Mashantucket Pequot Museum

Ledyard, Connecticut

Ove Arup and Partners (Arup) was contracted in 1993 to provide structural engineering services for a new museum and research facility for the Mashantucket Pequot Nation. The new 308,000-sq. ft. facility rests on the tribal reservation in Ledyard, CT. The goal was to create a major resource to study and promote American Indian Heritage, scholarship, and cultural preservation and to relate the story of the Pequots through an innovative and forward looking design. Well-known museum architects, Polshek & Partners, NY, were chosen to lead the design.

The creation and construction of the museum resulted from a twenty-two year old dream and desire of a handful of tribal members to tell the story of the Pequots. The Pequots' desire for the building to merge with the natural form of the landscape governed the architectural form of the building.

Incorporating the latest in archival and exhibitory technology, the building developed into five distinct, yet interconnected, structures stretching over 800'. Each of the structures served a

different function within the center. The first four structures above are contiguous and separated by 8” wide seismic joints.

The 5-story “Bar” building, a linear structure, houses the administrative offices, research, archaeological preservation, laboratory facilities, and soon to be the largest Native American library in the country.

The two-story Museum Building, an organic form, accommodates the exhibits, including a re-creation of a 17th century Pequot village and two circular “War Theaters”. The roof of the museum is a stepped terrace with differing landscapes progressing from east to west, with much of the interior space double height for exhibitions.

The Gathering Space building, a 170’-0” diameter x 60’-0” high partly glazed building, contains the main entrance and ticketing, performance auditorium, dining, and catering facilities. The Gathering Space provides the point where visitors access all areas. A 75' high glass hall serves as the architectural focal point of the building and as the main entry, the form based on the strategically offset semi-circles of the 1630s Pequot fort at Mystic. The original fort is highly symbolic and central to Pequot history.

A 210' high observation tower functions to punctuate the overall building's architectural statement. The Tower is semi-enclosed by stone and contains only a stair, an elevator, and an enclosed observation deck at the top used for viewing the surrounding countryside and the reservation. The tower operates as the southeast visual anchor of the building. Its aspect ratio is 14:1.

The Central Utility Plant (CUP) Building, a remote one-story building built underground on three sides, contains chillers, boilers, generators and other MEP equipment. The CUP connects to the main building by a tunnel.

Design Challenges

The client had already retained the exhibit designers before the building form had been fully defined. They assisted the client in creating the different chronological exhibits that ranged from the ice age to the present day and graphically told the story of the Pequots.

The landscape architects were responsible for creating the different flora of the stepped terrace over the museum as well as the landscaping around the buildings.

A major challenge for the geotechnical engineers was providing an efficient drainage system for the ground surface water given the large expanse of the structures. Providing HVAC services to the remote ends of the building given the plant room locations within it was also a challenge for the MEP engineers.

Although Arup's responsibility was primarily to provide structural engineering services, the responsibility extended to provide a fire engineering study for the Gathering Space.

> **Jurors' Comments:**
> A complex mix of structural solutions to the architect's design. The use of fire engineering to preserve the use of exposed structural steel in the gathering space while at the same time saving the owner $750,000 is worthy of note. A project of obvious architectural significance supported by engineering ingenuity.

Structural Design

Expansion joints were provided at pre-determined locations to separate the "independent" buildings, although due to its configuration, part of the Museum structure is tied to the Gathering Space structure.

The Bar Building, a simple steel framed building, tied to the retaining walls for the two lower floors and a standard beam/column construction above the third floor. Moment frames in both the east-west and north-south directions provided lateral stability for the building. A full 3-D model was developed and analyzed for lateral loads (including torsional seismic forces) and resulted in the provision of a maximum expansion joint of 8". The provision of a heavily loaded library on the fourth floor contributed significantly to the expansion joint width especially under seismic loading.

The western half of the Museum, a 2-story structure with two 2-story high 60'-0" diameter circular concrete walls, forms the War Theaters and a single story wall on the west side. Steel framing on top and between these structures support the roof and floor structures. The west side wall and the 2-story high concrete walls of the War Theaters provide the resistance for the lateral forces for this building. The lateral load resisting system was complicated by the stepped nature of the Museum roof slab. Because of this, seismic loads were carefully analyzed in a 3-D model that included the round concrete structures required to provide stability, finding that the asymmetrical location but substantive circular forms of the War Theaters efficiently resisted the high roof loads comprised of assembly, soil, and snow loads.

Combining simple conical and cylindrical shapes, truncating them by angles off the horizontal and then offsetting the two halves of the resulting circular base developed the geometry of the Gathering Space. The result is a 192' center span 3-dimensional truss stabilized by the roof beams it supports. A combination of moment frames and braced frames for the southern half of the space and moment frames and the concrete walls of the Museum to the north and east provided the stability for the Gathering Space glass structure.

A full 3-D model was developed for the analysis of the Gathering Space structure because of its extremely complicated arrangement.

Due to the size and unique shapes of the Gathering Space and Tower, CPP in Boulder Colorado arranged a wind tunnel. The results were used in the structural analysis to alter the assumed loads derived from the Code. Qualitative studies of snow deposition were used to supplement minimal loads calculated per the Code, particularly helpful in identifying areas subject to additional snow-drifts.

To achieve the architectural expression of exposed steel in the Gathering Space, Arup Fire conducted a fire study for submission to Code officials. The results of the study indicated that the required two-hour rating was achieved given the nature of the building and any conceivable fire loads. The results were accepted and the result was elimination of fireproofing of the steel and consequent savings of $750,000 for the Owner.

The complex geometry and large forces from rigidly connected framing members particularly challenged the design of the architecturally exposed roof connections.

In order to provide the long clear spans in the Gathering Space and lateral stability for the glass roof, the roof-framing members typically carried both axial forces and bending moments in both principal axes. At the end of the bifurcated shaped arch, as many as nine members converged from different angles into one rigidly connected joint. The amount of weld metal used for each of these "bell" connections estimated by the steel fabricator to be over 1000 lbs.

Braced frames in the east-west and northwest-southeast directions and moment frames in the north-south direction provide the lateral resisting system for the Tower. Here also a 3-D model for the analysis was created because of the extreme aspect ratio of 14:1 of the structure. Surprisingly, because of the braced lateral support system used, the Tower was relatively stiff, with deflections well within acceptable limits. The wind tunnel investigated a separate aero-elastic model of the Tower. The results indicated uncomfortable accelerations at the Observation Deck in wind speeds higher than about 20 mph. The client was advised and decided to limit access to the Tower when wind speeds exceed this amount in future.

Due to the complex geometry, the usual tolerance requirements specified by the AISC Code of Standard Practice were not applicable. As a compromise for buildability, we reanalyzed the Gathering Space structure and determined that tolerances 10% below AISC standards were structurally acceptable. This meant, however, that the design team had to examine each joint to determine the maximum allowable tolerance in terms of the structural forces and architectural requirements. The erection of the Gathering Space was monitored vigorously to ensure the erected structure would meet the project tolerance requirements. To monitor progress of the erection and surveying of the Gathering Space structure, the Construction Manager built a 1/8" scale model and each member of the model highlighted as it was erected in the field. We were intimately involved in the rigorous survey regime that determined locations before and after welding for each of more than 500 points. Even though tolerances were exceeded at several locations during construction, the design team backchecked the design with the given information to verify that the roof structure was not overstressed.

In one of the most impressive results, surveys before and after removal of the falsework for the 192' roof arch determined that the unshored structure was within 1/16" of calculated deflections.

The museum was officially opened on August 10, 1998 in a ceremony that included traditional Native American rituals and congratulatory messages from the President of the United States and other tribal nations.

Arup was part of the design team led by Polshek and Partners that included Exhibit designers, Design Division, Inc., MEP and fire protection engineers Altieri, Sebor Weiber, Landscape architects Office of Dan Kiley, and other consultants.

Mashantucket Pequot Museum, Ledyard, CT

Owner: Mashantucket Pequot Museum

Architect: Polshek & Partners, New York, NY

Structural Engineer: OVE Arup & Partners, New York, NY

Fabricator: Cives Steel Company, Roswell, GA *(AISC member)*

Erector: Berlin Steel, Berlin, CT *(AISC member)*

Detailer: Computer Detailing, Inc., Salt Lake City, UT *(NISD member)*

General Contractor: Pavarini Construction Co., Ft. Lauderdale, FL