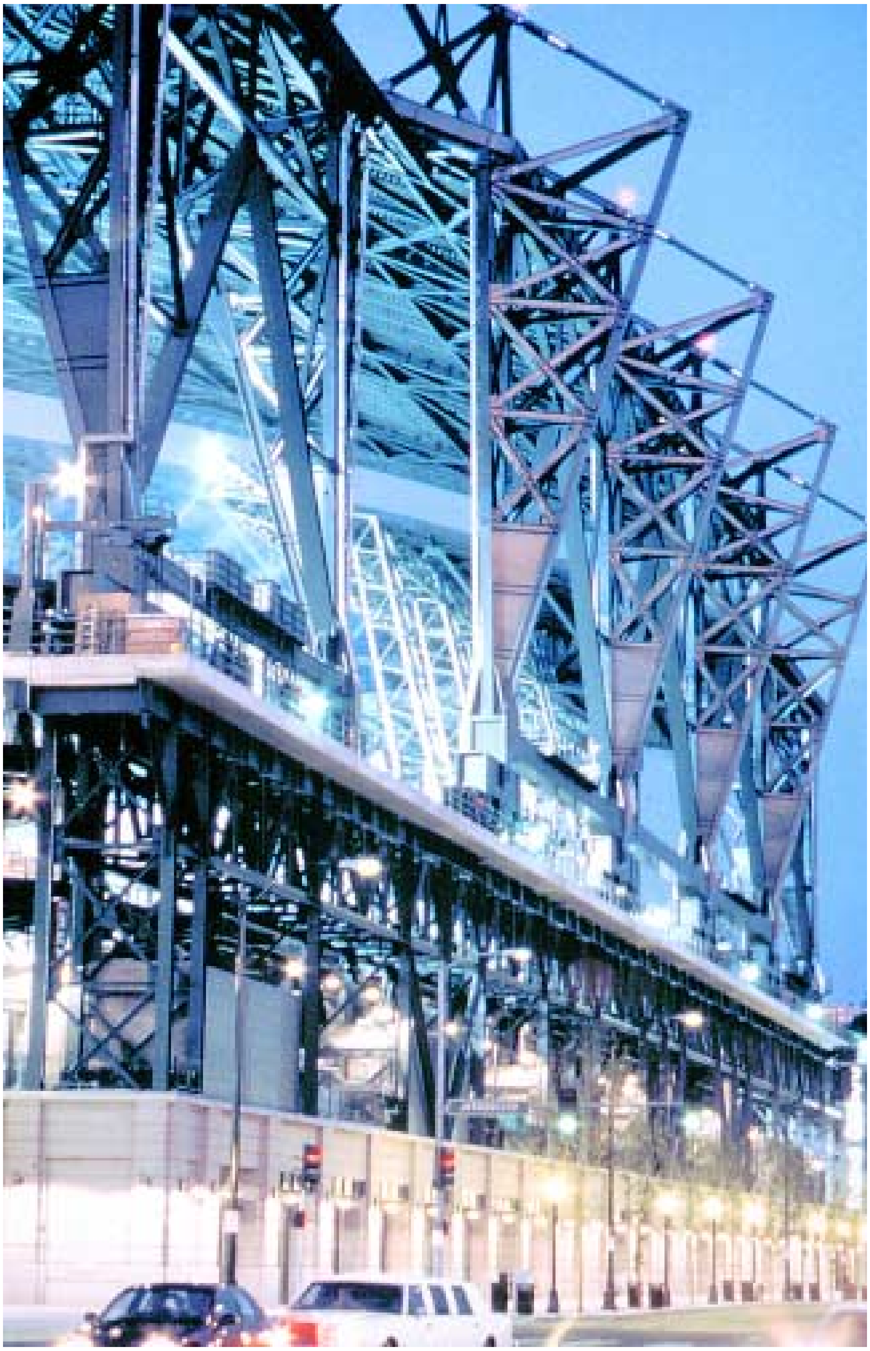
Engineering Awards of Excellence

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"

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.

- 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

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