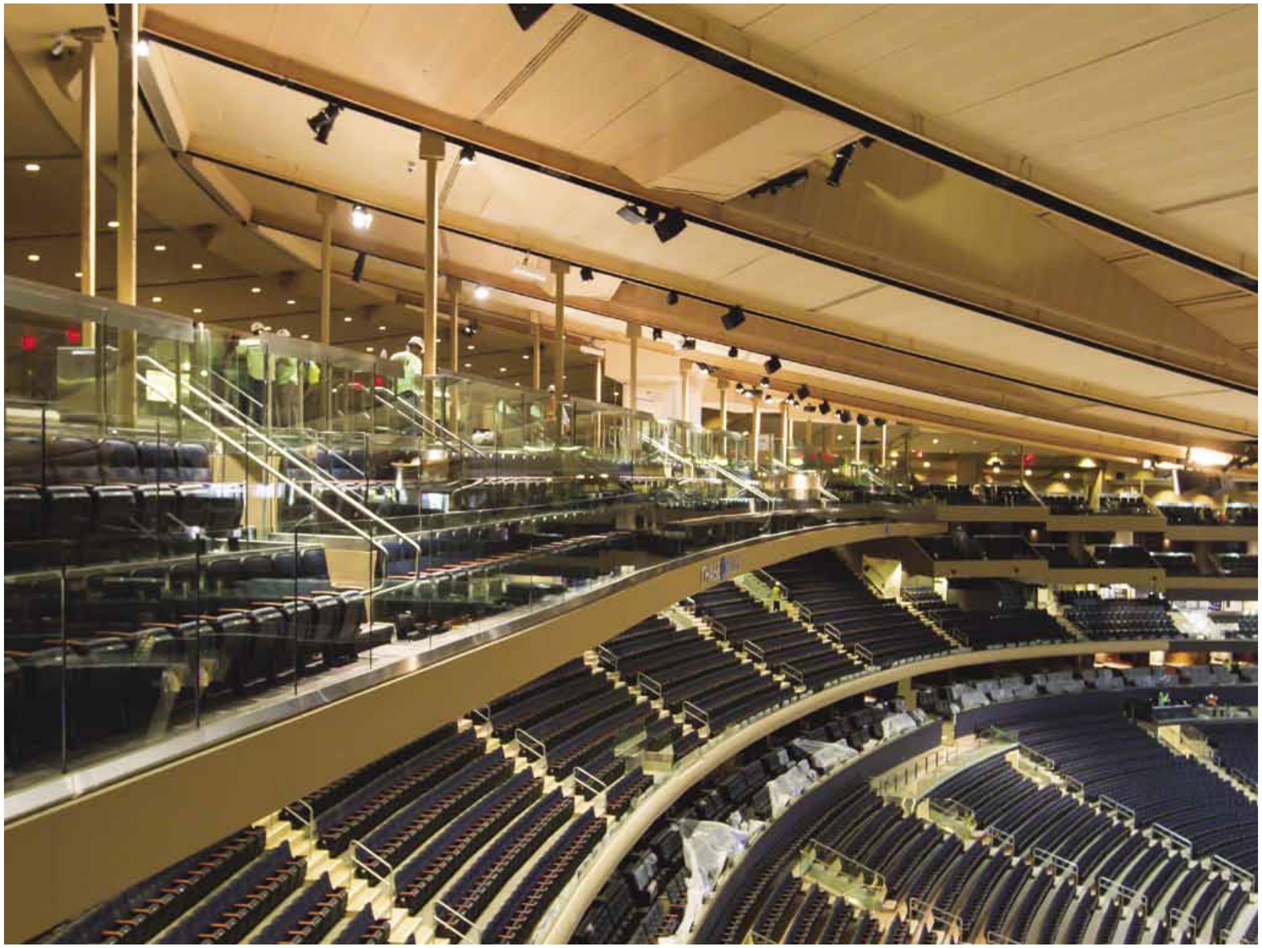


The need to re-work the seating areas of Madison Square Garden was one of the main reasons for the renovation. New suites were placed between the lower and upper levels and a new "bridge" that provided upper level seating was hung from the roof structure.

Madison Square Garden

Renovating and expanding "the world's most famous arena" while it was still open and operating required close collaboration between everyone involved—and some creative engineering to add a new interior level for fans.

FOR ANYONE AWARE OF ITS legendary history, Madison Square Garden exudes images of activity and excitement. It is home to the New York Knicks, New York Rangers, New York Liberty, and is a setting for the most sought-after rock concerts and family shows held in the Tri-State area. Located on Seventh Avenue between 31st and 33rd streets in Manhattan, it sits directly over Pennsylvania Station, providing easy access to several modes of public rail transportation. These virtues notwithstanding, it is a forty-year-old venue that needs to compete with today's newer arenas. So in 2003 its owners, The Madison Square Garden Company, challenged Toronto architects Brisbin, Brook, Beynon (BBB) to update it, beginning a decade-long renovation and expansion project that transformed the building into a state-of-the art arena.

The original 1968 building is the third bearing the Madison Square Garden name. Constructed as a cylindrical building whose roof is suspended by steel cables from a perimeter compression ring, it allows a wide-open stadium floor elevated five stories above street level. Above that, three tiers of seating accommodate up to 20,000 people depending on the event.

In 1991, a $200 million renovation project changed some of the upper level seating into enclosed luxury suites for corporate and sponsor purchase. Less than a decade later it was clear that another upgrade was needed to locate the pricey suites closer to the arena sports floor. By including upgrades to the broadcasting and electronic systems, "hardening" the building for post 9/11 security measures, improving the lobby and flow of people, and enhancing the general interior character, the owners were committing to a nearly $1 billion project that would take seven years to design and three years to construct—all while keeping the arena operational during the hockey and basketball seasons.

After several years of analyzing options, the design team led by BBB began work in earnest with the engineering firm who designed the original structure, Severud Associates. It became quickly apparent that some of the most attractive features of the building would become some of the biggest challenges of the renovation. Its location above four levels of underground rail lines meant that the existing columns and footings supporting the building were fixed in strategic locations between train tracks, eliminating any opportunity to strengthen or add columns.

The rework of the seating areas needed to address the existing structural constraints but still achieve the desired outcome of an improved seating experience. The existing seating was defined by an upper and lower bowl section and it was determined that the best place for the new suites was in between these two sections at the seventh level of the building, two levels above the arena floor. The lower seating section was essentially re-used, but the existing upper section was removed and the new suites built above the lower level seating. New, steeper upper-level seating was then built above the new suites that sloped up to be 13 feet higher than the previous top of the upper seating area. This put it at nearly the same level of the existing roof, so the perimeter of the roof was literally removed and raised to be less steep but still supported by the existing cables. This created the needed clearances and sight lines, but new column locations required by this rearrangement had to be supported on transfer girders to spread the load to the existing structure below in the rail transit areas.

Perhaps the biggest single challenge, yet the most defining change to the arena is the addition of two new promenade and seating bridges located

Below The short time intervals available to perform construction work meant that multiple subcontractors and multiple pieces of equipment were used simultaneously while the arena floor served as the staging area for the transformation of seating zones.

Facing, clockwise from top The new "bridge" areas at the upper level give spectators a view directly onto the arena and are stabilized against movement using Tuned Mass Dampening (TMD) devices. The installation of a new, larger scoreboard and LED video monitors meant that additional weight needed to be accounted for and transferred to the steel cable roof system and supported by steel trusses along the perimeter. Upper-level seating behind the new bridges still provides a full view to the arena floor due to the raised roof along the exterior. Large LED monitors provide information from the scoreboard that is screened from view in some locations.

at the tenth level—one on the north and one on the south side above the playing surface. Their purpose is twofold: create more seating to make up for what was lost in the suite construction, and include a dramatic walkway where fans can look down at the events below. The problem was how to support the bridges without adding new columns that would interfere with sight lines for seats on the lower levels. The answer: suspend them from the roof. If this were a new building, the structure would be designed to accommodate the weight of the bridges plus the live load of the spectators. As an existing building with limited ability for structural changes, adding the new bridges required creative problem solving and detailed engineering.

Cawsie Jijina, the Severud principal overseeing the structural work at Madison Square Garden, led his team to first look at the space above where the bridges would reside. They saw that all of the arena's air, water, and electrical systems convened there as well. That precluded the use of solid members, so twenty pairs of 4-foot-6-inch-tall steel trusses were designed that pick up the weight of both bridge decks, while allowing the various MEP systems to thread through them. Ultimately, the trusses deliver their load to the existing suspension cables supporting the roof. Each truss is fabricated from approximately 6 tons of grade 50 (A992) steel using double L4x4x½ chords and 2 L3x3x⅜ diagonals. The trusses are positioned directly under the existing roof beams (situated on top of the roof support cables) and support W14 and W16 members plus cables that hang intermittently to support the 230-foot spans of the two new bridges. Each massive bridge is constructed of approximately 76 tons of structural steel covered with 134 tons of 4,000-psi lightweight concrete; they comprise an area of approximately 6,700 square feet each. In addition to its self-weight, each bridge is capable of supporting an additional 600,000 pounds of occupants, evenly distributed.

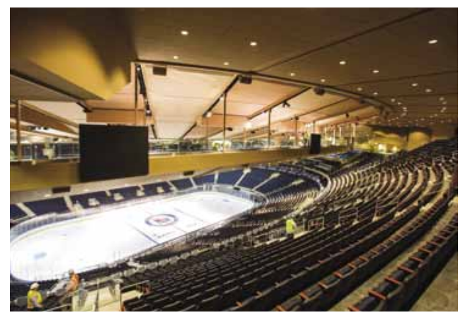
In their static condition, the design of the bridges is quite adequate with the appropriate safety factors worked in. But one of the more critical aspects of the structural design is the dynamic behavior of the bridges. Because the bridge is ultimately supported by the existing cable roof system, rhythmic movements, such as those generated by an excited crowd during a rock concert or sports event, can potentially cause motions strong enough to make spectators uncomfortable. Rather than adding brute force stiffness (and additional weight) to the roof, truss, and bridge decks, the project's engineers sought a more elegant and cutting-edge design solution. RWDI Motioneering, based in Ontario, Canada, worked with the design team to devise a "tuned mass damper" (TMD) to dissipate the dynamic energy. Each of the two bridges received five TMDs, three on the front (arena side) to combat vertical motion and two on the back (street side) to combat horizontal motion, with all five working simultaneously to control roll.

Each TMD comprises 9,000 pounds of stacked lead plate, a crank-shaft and two hydraulic pistons (weighing approximately 1,000 pounds) that translate rotational motion into vertical motion (similar to the engine of a car). The lead plates are put into motion by the motion of the spectators during an event. The entire TMD system is calibrated to oscillate (move) in the opposite direction as the loading frequency caused by the spectators. Thus, this opposing motion caused by the TMD will weaken the loading frequency, dissipating the energy and dampening the perceivable motion throughout the entire structural system. Monitoring the TMDs during events has verified their satisfactory performance.

Turner Construction served as the project's overall construction manager and began during the design phase to review constructability issues. Because of the extent of the work and the limited construction time of only 20 weeks between sports seasons per year, three separate and distinct phases each were planned as a stand-alone project that left the building fully functional until the next one started. Hence, the driving force for the renovation wasn't budget as much as a critical time schedule. Major-league sports team schedules were pre-determined so the building absolutely needed to be open in time for the games to take place and the public to attend. Consequently, in each of the three phases construction crews worked 24 hours a day, six days a week to maintain the schedule.

In order to further avoid any chance of delays the steel work was separated out into five different subcontracts that required additional coordination, particularly for the new tenth-level bridges. For each bridge, the steel structure was fabricated by one steel company, the cables to hang it from above by a second, and the trusses that it all hung from by a third. This divided production up to increase capacity, but added to the effort needed by the engineers, contractors, and construction manager to carefully check and coordinate everyone's drawings, not to mention coordinating them with mechanical and electrical equipment that was already in place.

In the end, it the project's prolonged effort and extra coordination work was well worth the wait. The design team, construction team, and owners have created what is truly one of the most exciting sports and entertainment venues anywhere—one that wouldn't be enjoying the popularity it sees today without the finely engineered structural steel trusses, members, and cables that gave it new life. ☐



This page and opening spread: Rebecca Taylor/MSG Photos; facing page: The Madison Square Garden Company

MADISON SQUARE GARDEN

Location: **4 Pennsylvania Plaza, New York, NY**
Owner: **The Madison Square Garden Company**, *New York, NY*
Architect: **Brisbin Brook Beynon**, *Ottawa, ON*
Structural Engineer: **Severud Associates**, *New York, NY*
Mechanical Engineer: **M-E Engineers**, *New York, NY*
Construction Manager: **Turner Construction**, *New York, NY*
Curtain Wall Consultant: **Israel Berger & Assoc. Inc.**, *New York, NY*
Structural Steel Fabricator: **Helmark Structural Steel Inc.**, *Wilmington, DE*
Structural Steel Erectors: **W&W Steel, LLC**, *Camden, NJ*; **Stonebridge Steel Erection Co., Inc.**, *South Plainfield, NJ*; **Titan Erectors, Inc.**, *Woodcliff Lake, NJ*
Miscellaneous Iron Fabricators and Erectors: **Empire City Iron Works**, *Long Island City, NY*; **FMB Inc.**, *Harrison, NJ*
Curtain Wall Erector: **W&W Glass LLC**, *Nanuet, NY*
Metal Deck Erectors: **W&W Steel, LLC**, *Camden, NJ*; **Stonebridge Steel Erection Co., Inc.**, *South Plainfield, NJ*; **Titan Erectors, Inc.**, *Woodcliff Lake, NJ*