
MKA/Michael Dickter

Creative ARTS

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The structural design team for SFMOMA's new addition got creative with steel to accommodate tight building foundation and footprint parameters.

OPTIONS FOR THE STRUCTURAL DESIGN of the San Francisco Museum of Modern Art (SFMOMA) expansion were constrained from the beginning.

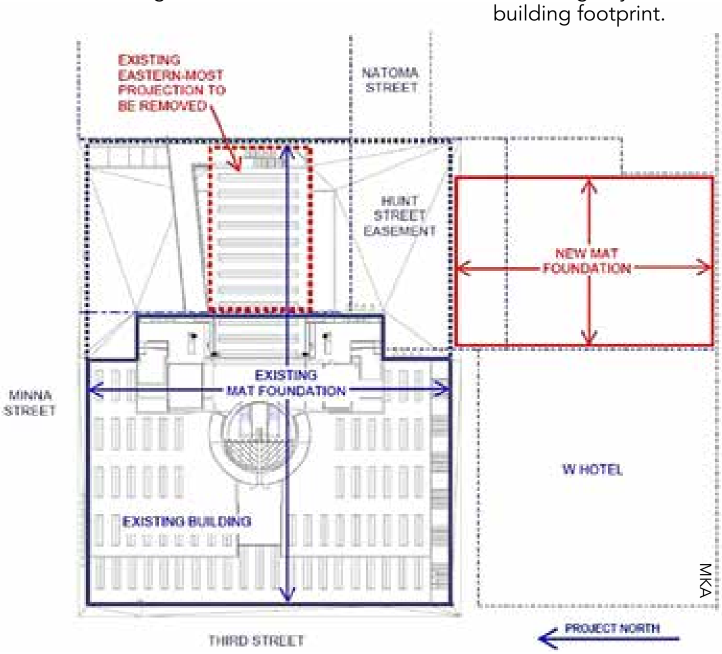
The unique site and foundation demands, along with compact architectural programming, limited possible structural strategies. However, in the end, these constraints sparked an innovative design using structural steel that met the economic and structural performance requirements, and helped make the largest modern art museum in the U.S. a resounding success.

Foundation Constraints

The original SFMOMA, designed by Mario Botta/HOK (architect) and Forrell-Elsesser (structural engineer) in 1992, included a 4-ft, 6-in.-thick mat foundation. This foundation was extended beyond the footprint of the superstructure to allow for an expansion of similar height to the existing building, which is approximately 100 ft tall.

Buckling restrained braced frame on south façade along Howard Street.

Site plan with existing SFMOMA and mat slab extending beyond the building footprint.

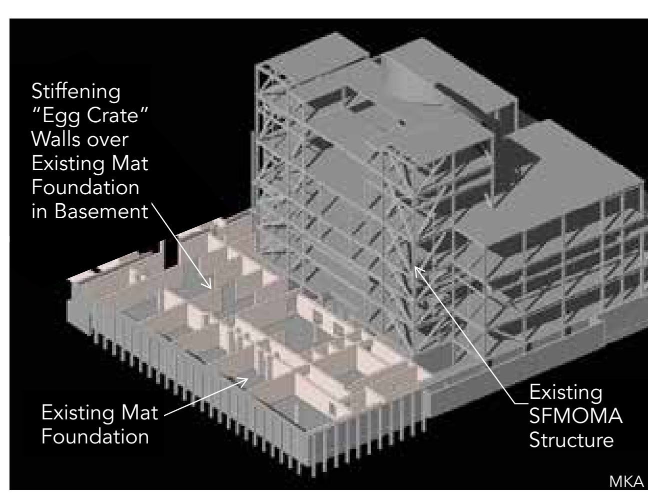


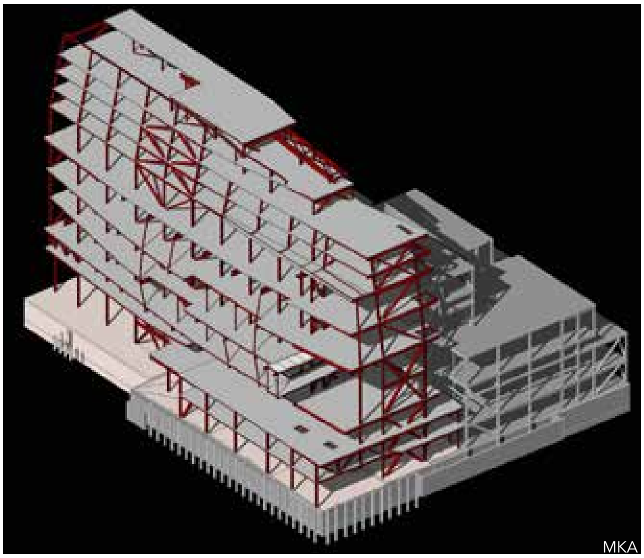
Stiffened egg crate walls in the basement over the existing mat foundation create an occupied foundation.

So when the design architect, Snøhetta, unveiled their vision for a *200-ft-tall* tower nestled directly east of the existing building and spanning two blocks from Minna Street to Howard Street, it became apparent to the design team that the existing mat foundation would struggle to support the proposed structure. Accommodating a building twice the height of what was originally anticipated would require a 6-ft-deep mat foundation. However, demolishing the existing mat foundation would pose too great a risk for the existing building due to loss of flexural continuity, and the option of drilling large piles through the existing mat foundation was not economically feasible.

Therefore, the proposed solution was to retain the existing mat foundation and support the expansion on a series of full-story-deep concrete stiffening walls with embedded steel columns. The "egg crate" solution, as it was referred to by the design team, would create an occupied foundation or stiffened box—the existing mat foundation as the lower flange, the interior walls as stiffened webs and the grade-level slab as the upper flange. The walls would be positioned to spread load from the superstructure while still allowing for the architectural program within the basement.

By spreading the load with a stiff network of walls, the existing reinforcement in the mat foundation could be reused and the large loads could be distributed to allow for epoxy doweling between the new and existing structure. The steel columns were encased in the walls with steel fins and headed studs to effectively transfer and spread the large forces from the superstructure to the foundation.





▲ Superstructure over stiffened walls and mat foundation.

➤ A steel column with studs to transfer load into the egg crate walls.

▼ Embedded steel columns in the egg crate walls.

▼ The museum's ribbon-cutting ceremony.

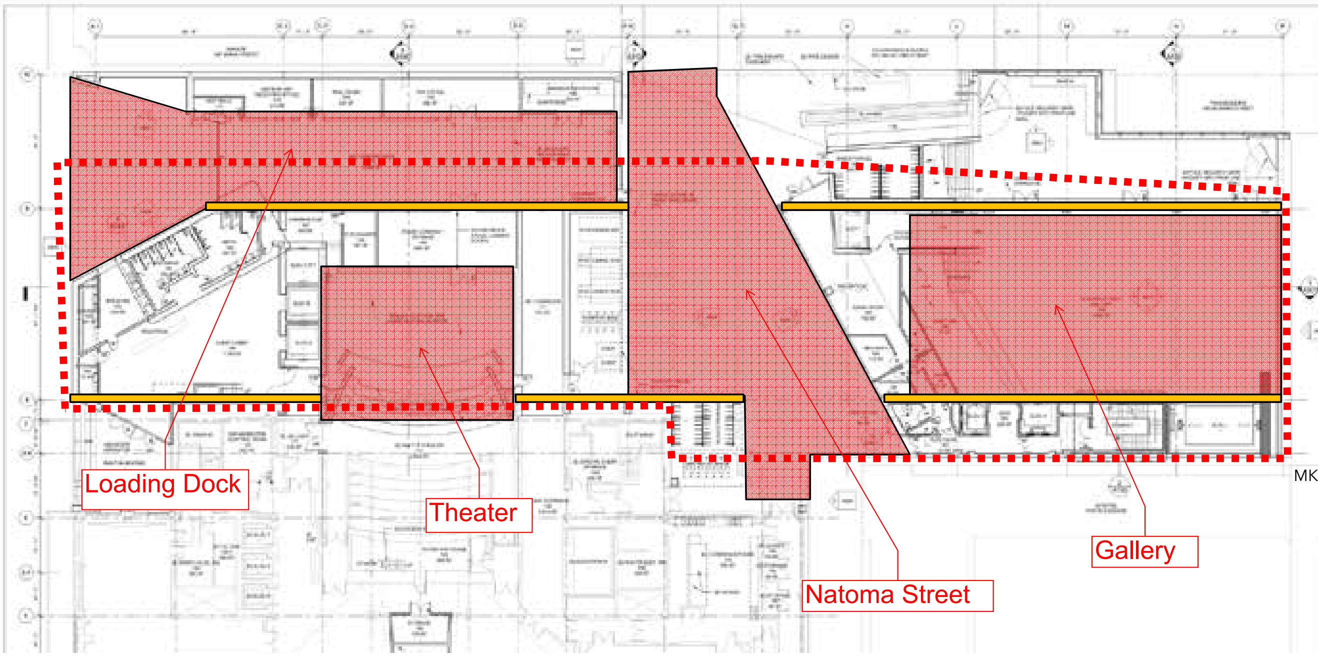
Architectural Constraints

In order to fit in the long, narrow site, the proposed expansion could be no wider than approximately 100 ft and extended nearly 300 ft in length. This aspect ratio forced all steel columns to be positioned along the exterior of the building for open galleries and circulation. In addition, the building bridges over Natoma Street, as well as a loading dock, further restricted column placement.

The combination of these constraints meant that the number of columns had to be minimized. Therefore, the load per column would be much higher than "typical" for a 200-ft-tall tower—which only further complicated the foundation egg crate design. At the most heavily loaded columns, large cruciform-shaped walls were required to spread out the load and to avoid overstressing the existing mat foundation in flexure and shear.

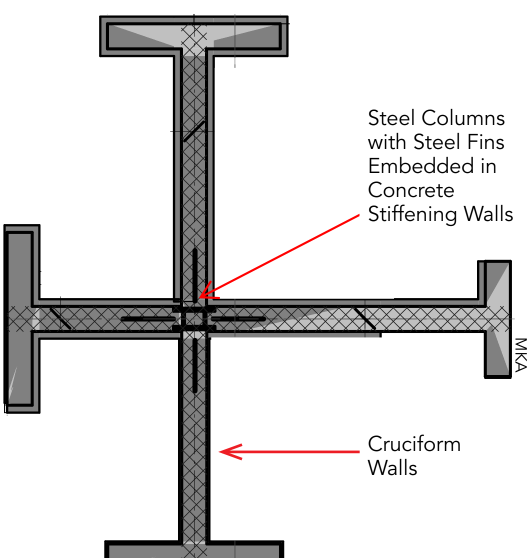
Lateral Bracing System

Given the long spans required for the open galleries—up to 55 ft—and the desire for a 20-ft cantilever on the east side of the building, structural steel was the logical choice. Built-up plate girders up to 90 in. deep were required to achieve the spans and ensure acceptable vibration performance, and braced frames were strategically located in permanent partition walls along the length of the floor plate.



▲ Ground-level plan. Shaded red zones indicate column-free zones along the two-block site. The red dashed line is the building above, and the orange walls indicate the primary bearing lines where steel columns could be positioned.

▼ Close-up plan of cruciform wall to distribute column force.



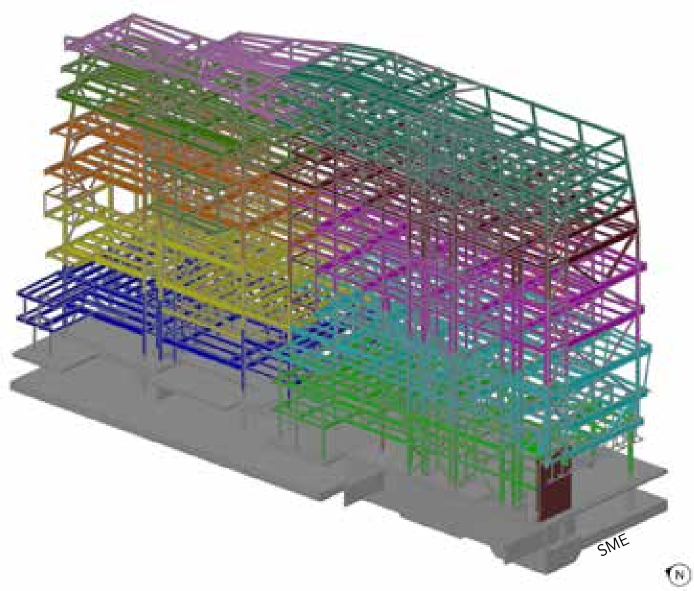
▼ Long-span built-up plate girders and cantilevers for open, column-free galleries.

The design team explored various lateral bracing systems that would be compatible with the structural steel gravity system. Buckling restrained braces (BRBs) was selected for two important reasons: They provided the highest level of ductility to minimize loading on the existing foundation, and they allowed for better "tuning" of lateral stiffness to combat torsion under wind and seismic loading. The building employs 156 BRBs in all.

Structural engineer MKA worked with the BRB supplier, Corebrace, to more accurately define the yielding and overstrength characteristics of each brace, and brace connections were developed with both pinned and welded types for aesthetics.

Nonlinear Analysis

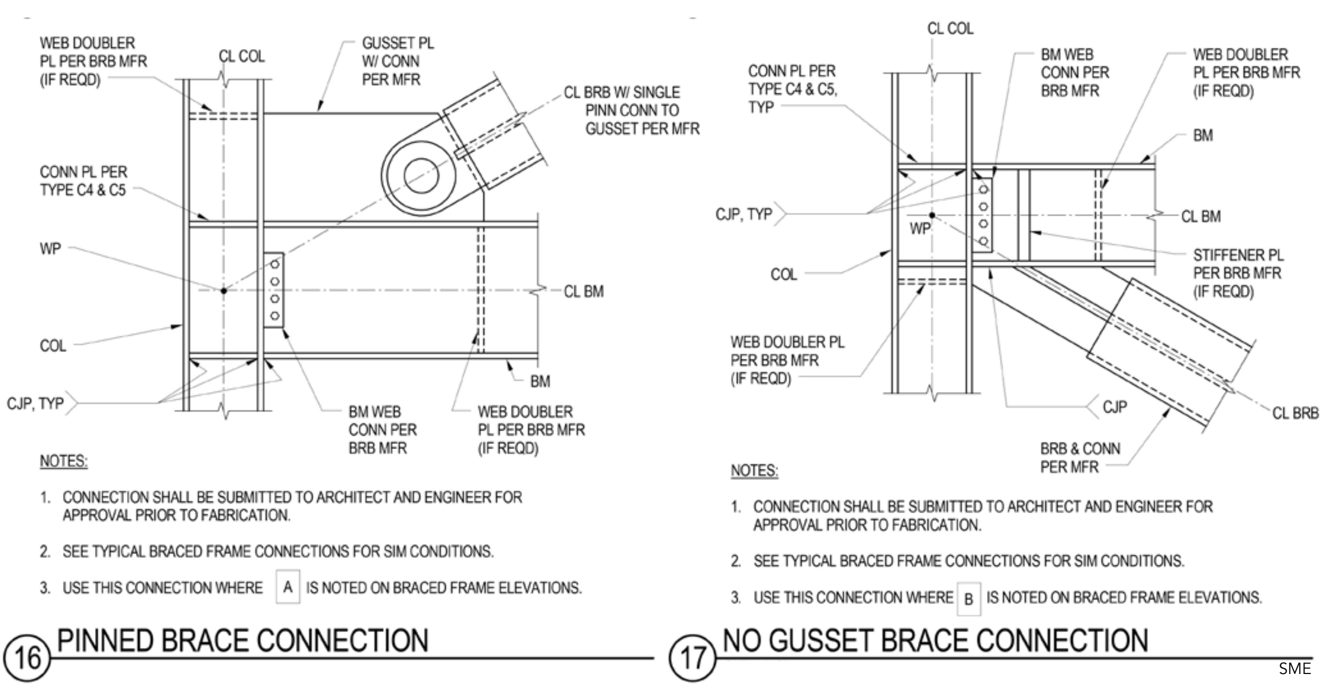
The AISC *Seismic Provisions for Structural Steel Buildings* (ANSI/AISC 341, available at **www.aisc.org/specifications**) allow for a nonlinear analysis to decrease predicted seismic induced column demands, including demands at the foundation—and this document was critical to the success of the museum's design. If the columns were designed for the simultaneous yielding of all of the braces for the full height of the building, as with a traditional capacity design approach, the axial demands at the base would be too large to resist by the egg crate walls and new foundation. By analyzing the nonlinear behavior of the structure during maximum seismic ground shaking, MKA was able to



▲ A 3D model showing the steel framing system.

➤ A living wall at the sculpture terrace.

▼ BRB bracing connection details.



more accurately predict the column forces and the demands for the column-to-foundation connections.

Geotechnical engineer Treadwell and Rollo provided MKA with 11 pairs of site-specific ground motions, and MKA analyzed the performance using a nonlinear model of the building. By adjusting the BRB distribution and sizes, MKA tuned the building to dissipate sufficient seismic energy and meet all strength and deformation requirements.

Erection Process

Adopting a design-assist mindset, MKA and erection engineer Hassett Engineering collaborated early in the schedule to develop connections that would accommodate safe and efficient erection. 3D modeling was implemented during preconstruction and continued through the construction phase. This was critical not only for MEP clash detection but also due to the complex 3D geometry of the exterior curtain-wall-to-steel interface.

➤ The completed building, which incorporates 4,600 tons of structural steel.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As the site was bordered by existing buildings to the east and west as well as roadways on the north and south, there was no lay-down area outside of the project footprint. There were three truck unloading areas, all on active roadways or alleys, and deliveries were limited to one truck at a time. Three or more trucks a day were staged at remote locations, and each steel delivery had to be properly sequenced to go from truck-to-hook and erected into place.

Given the site, foundation and architectural demands, structural steel—4,600 tons of it—was the best framing choice to bring the project together. Its light weight and high strength-to-weight ratio decreased gravity loads at the foundation and minimized seismic mass. Structural steel also facilitated long spans over galleries and large cantilevers along the curved east façade and its incorporation into BRBs helped balance the stiffness of the long, skinny floor plates while also limiting the foundation loads under seismic forces.

Ultimately, these demands were met with an economical structural steel design, which included an innovative foundation concept and brought Snøhetta's vision to life. The expansion, which opened last year, is a timeless and inspiring design that enhances an already prominent museum and creates a new icon for San Francisco. ■

Owner
San Francisco Museum of Modern Art

General Contractor
Webcor

Architect of Record
EHDD, San Francisco

Design Architect
Snøhetta, San Francisco

Structural Engineer
Magnusson Klemencic Associates, Seattle

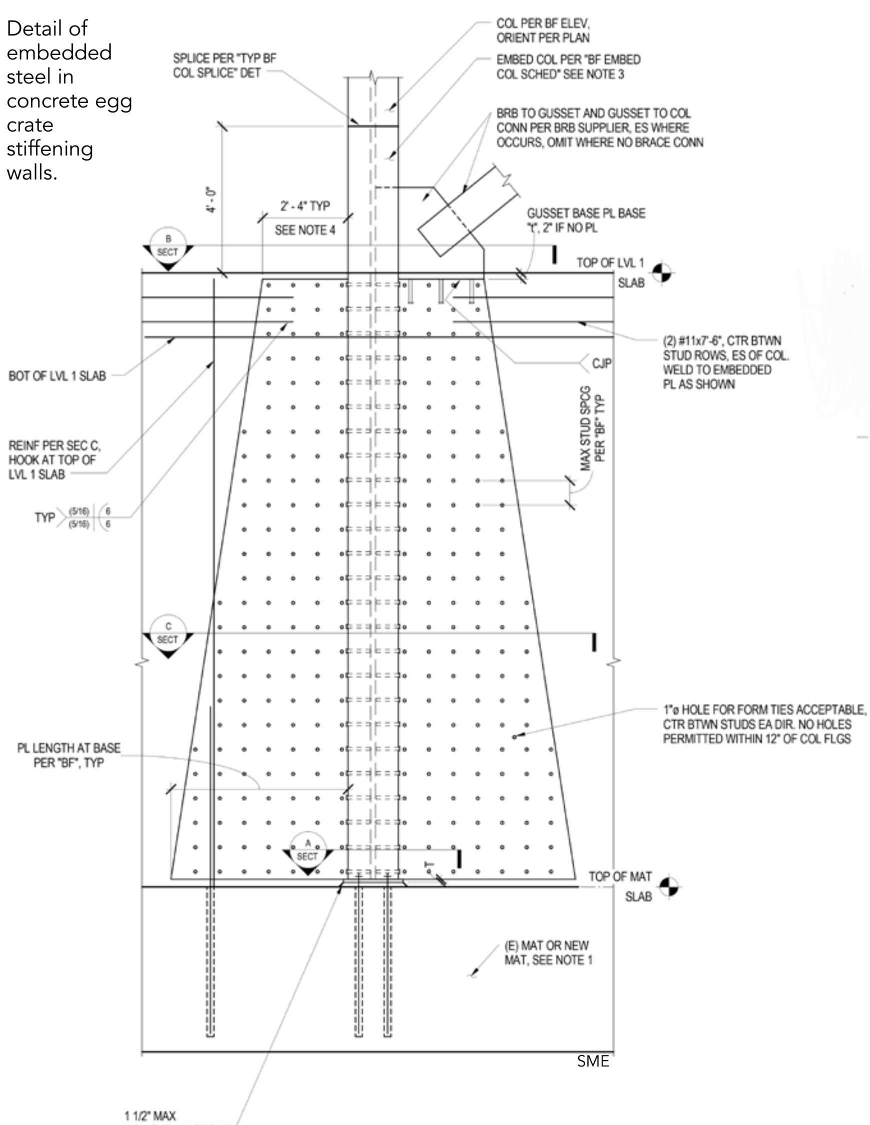
Erection Engineer
Hassett Engineering, Castro Valley, Calif.

Steel Team

Fabricator and Erector
SME Steel Contractors, West Jordan, Utah

BRB Supplier
Corebrace, LLC, West Jordan, Utah

Detailer
Pro Draft, Inc., Surrey, B.C., Canada



▼ Detail of embedded steel in concrete egg crate stiffening walls.