Forever de Young

Steel framing helps revive San Francisco's de Young Museum.

BY BRET LIZUNDIA, S.E.

IN OCTOBER, 2005, THE DE YOUNG MUSEUM WAS REBORN AS A STRIKING NEW COPPER-CLAD SAN FRANCISCO LANDMARK. Sixteen years had passed since the Loma Prieta earthquake damaged the original structure. Two bond measures barely missed obtaining the required two-thirds majority vote needed for public funding of a new building, leading to a subsequent private funding campaign. An international architectural design competition was won by Herzog & de Meuron of Switzerland. Lawsuits were filed by those concerned over a related parking garage and the modernistic building design, but they were eventually defeated. Finally, after six years of design and construction, the museum returns to its historical role as one of San Francisco's major cultural institutions and the key stop on the West Coast for major traveling art exhibitions.

The project had several components. The seismically deficient, programmatically inadequate existing structure was demolished. It was replaced with a new 258,000 square foot, three-story museum structure and a separate 33,000 square foot, 10-story education tower. Extensive landscaping improvements were made all around both buildings. The construction cost was $135,000,000; the total project cost was $202,000,000.

To bring the architect's vision to life, Rutherford & Chekene faced a number of structural design challenges. These included a highly irregular floor plan with a myriad of diaphragm openings, cantilever truss eaves projecting out from the building face over 62 feet, and interior bridges over 90 feet long. There were large interior landscaped courtyards, heavy live loads, building wings over 400 feet long with only 20 feet of connecting floor and roof diaphragm, and a significant quantity of non-orthogonal connection geometry driven by the architectural layout. A seismic isolation system in the main museum building helps

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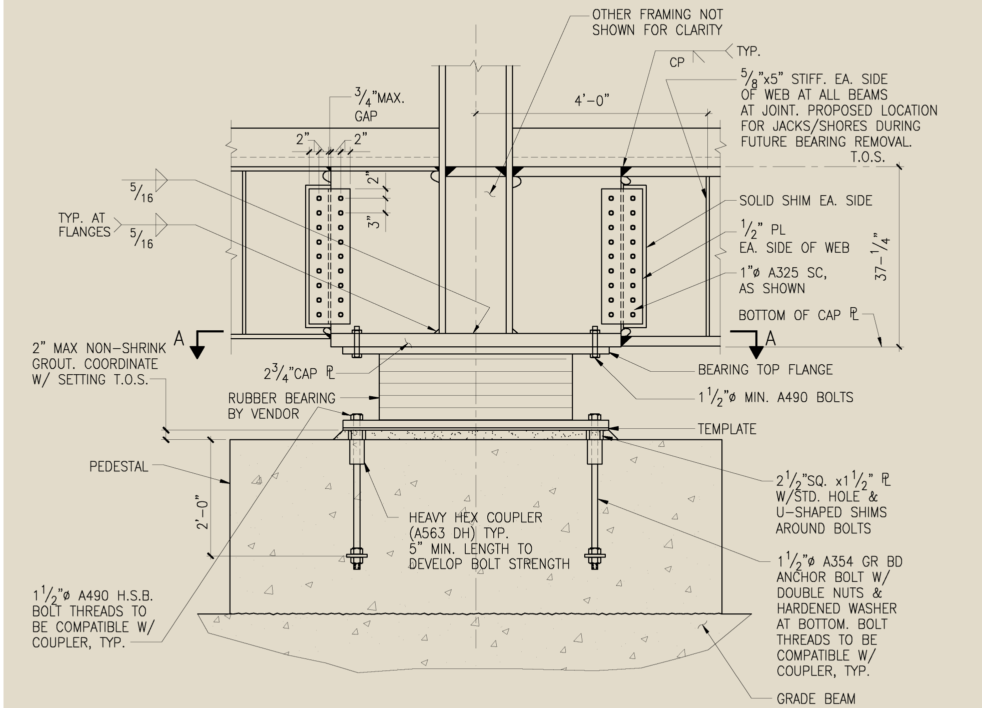


SECTION AT INTERIOR RUBBER BEARING

Above and Below: Seventy-six high-damped rubber elastomeric bearings made by Bridgestone Rubber of Japan function as part of a base isolation design that keeps building acccelerations below 0.5 g even in worst-case analyses.

to protect the art collection, and there is a twisting education tower with its warped façades and extensive glazing. The use of steel framing was critical to the success of the complicated project.

Seismic Performance Objectives

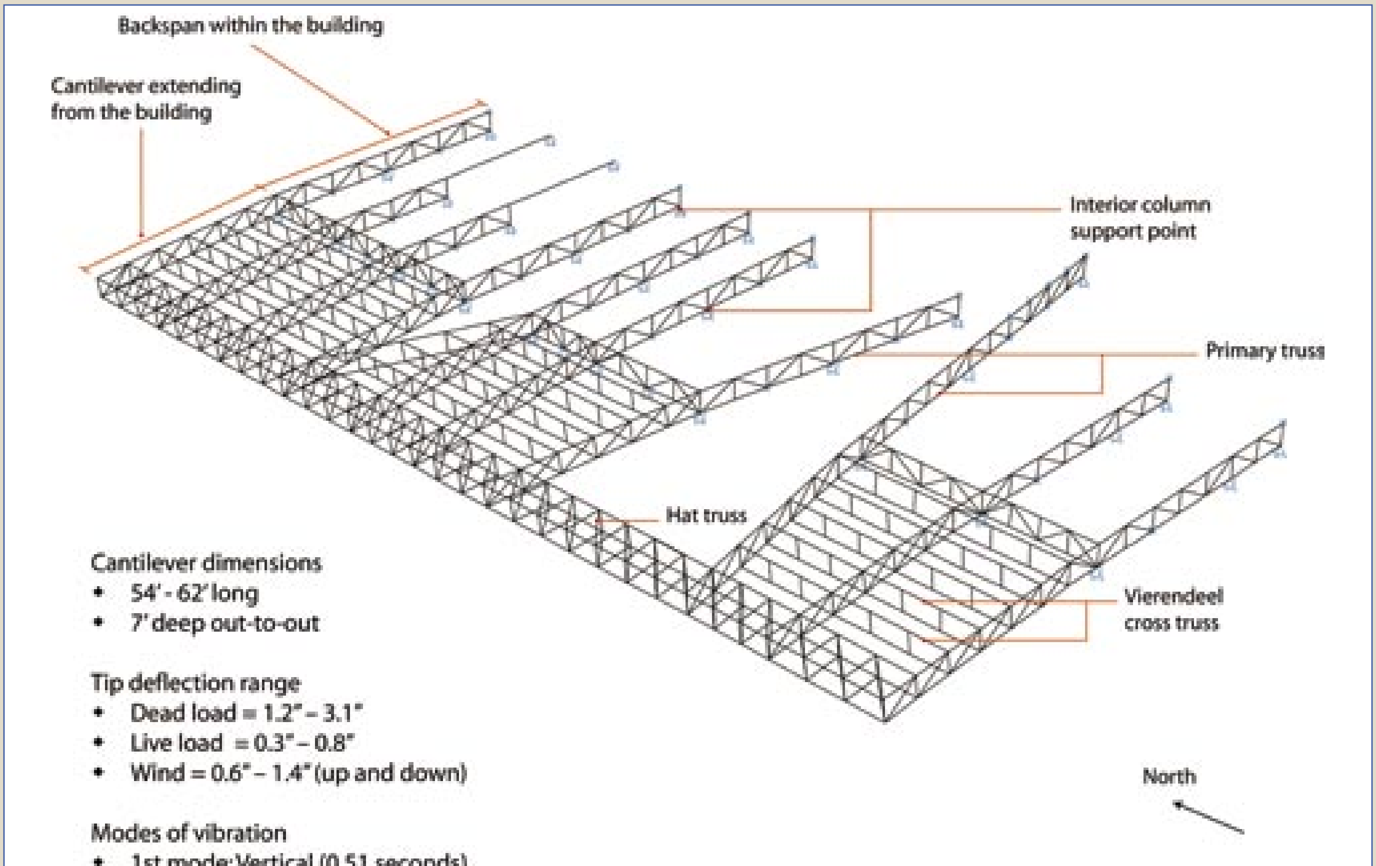
The museum building is seismically isolated to minimize damage to the art collection and to reduce the floor accelerations sufficiently so that conventional art bracing and anchorage methods may be used. Performance goals include reducing floor accelerations caused by the nearby San Andreas Fault down to 0.5 g or less in the Maximum Capable Earthquake (MCE) and to 0.4 g or less in a smaller M7.0 earth-

Above: One of 24 nonlinear fluid viscous dampers made by Taylor Devices of New York.

Cantilever Eaves

As a horizontal counterpoint to the vertical tower, a cantilevered eave extends west up to 62 ft outside the building to shade an outdoor patio for the cafe. It is clad in perforated copper, but the underlying structural ribs can be seen in silhouette. Each main exposed cantilever element is a truss made of welded wide flange shapes measuring 7 ft out-to-out vertically. Less expensive gusseted connections were used in the hidden interior backspan. At the exterior cantilever, Vierendeel cross trusses span north-south between the east-west main trusses and provide the supporting framing for the copper. Wind and earthquake loads parallel to the cross trusses are resisted by moment connections at the connections between the main trusses and cross trusses and by the bracing afforded by one of the diagonally oriented main trusses.

In addition to minimizing vertical deflections at the cantilever tip, a key design goal was to keep the modes of vibration of the eave structure well below the one second period threshold above which there is concern for resonance from wind excitation. In the final design, the first mode is vertical at 0.51 seconds and the second is horizontal at 0.45 seconds. Besides UBC wind load requirements for uplift, downward wind pressures were also included in the load cases, per recommendations from review of the wind provisions of various international codes.



CANTILEVER DIAGRAM

quake. To minimize damage and downtime, key structural elements such as the braced frames and connections between wings are designed to remain essentially elastic in the MCE, and other components are sized to require only limited ductility, with design requirements that typically exceed the 1997 UBC and 2006 IBC seismic isolation provisions.

Structural System

The isolation system bearings of the museum building rest on concrete pedestals located at the intersections of a grid of concrete grade beams which are founded in the native sand of the site. The bearings support a steel frame and concrete fill on metal deck floors and roof. Lateral loads in the superstructure are resisted by concrete shear walls at the basement and by braced frames at the upper levels. Story heights are tall, at 19 ft 6 in. at the basement, 19 ft at the first story and up to 26 ft at the second story. The footprint of the building is 420 ft in the east-west direction and 247 ft in the north-south direction. A large steel-framed cantilever roof extends out to the west of the building.

Going Steel

A steel-framed structure was chosen early in the design for the museum building due to the highly irregular geometry, long spans, and many floor openings present in the architectural design. Concrete would not have been cost effective due to the lack of regularity, large number of cantilevers and desire for relatively thin individual members. Concrete also would not have been practical for the large cantilever eaves, and steel framing was easier to modify as the architectural design evolved.

Initially, steel moment frames were considered for the upper stories of the building due to the number of window penetrations, but the amount of glazing was reduced in schematic design, so less expensive braced frames could be used. Despite the highly irregular nature of the building, torsion effects are relatively minor due to a well-distributed system of braced frames developed through careful coordination with the architect. Ordinary concentrically-braced frames were permitted, as they are designed to remain elastic in the MCE. Concrete shear walls in the basement story help to distribute seismic overturning forces, eliminating tension stresses at the isolation bearings in most locations and minimizing them in the remaining areas.

Small Links Between Wings

The museum building is divided into three parallel east-west oriented wings, all linked together by a single roof that symbolizes for the architect both the unification of the museum's diverse art collections and San Francisco's acceptance of diversity. This plan layout resulted in very small connections between the diaphragms of the individual wings at the roof and second floor. The 420-ft-long north and central wings, for example, are linked by a single 20-ft-long piece of diaphragm.

Rutherford & Chekene was able to reduce the predicted rotations in the links to acceptable levels and keep the structural elements crossing them elastic in the MCE through careful balancing of the braced frame locations in each wing, special details involving embedded steel floor plates for shear transfer, heavy W shapes for collector and chord forces, and detailed nonlinear time history analyses.

Long-span Conditions

To bring the park into the museum, there are extensive interior landscaped courtyards containing full-sized trees and giant tree ferns, atria, skylights and diaphragm penetrations. The architect also sought to open up the first floor public areas as much as possible by eliminating columns. A number of special long-span framing systems were needed. In some locations, plate girders support story-height trusses that in turn support open web long-span floor truss transfer girders. Interior clear spans exceed 90 ft.

In addition, over 500 brass floor grills, used to provide the under floor air supply desired for the tall galleries, were carefully located in the floor diaphragms to meet mechanical, aesthetic, and structural requirements.

Non-Orthogonal Connections

The architectural design involves extensive use of 10° and 20° acute angles in the plan geometry. Because of the large number and size of interior openings, there are many chord and collector locations requiring moment connections that pass through columns at the acute angles. A special family of non-orthogonal moment frame beam-to-column details was created to deal with these conditions. Similar sets of skewed framing details were developed for the connections between the steel framing and the isolation bearings.

Live Loads

The museum contains an unusually varied number of functions, including galleries, offices, a restaurant, stores, a large auditorium, carpentry shops, curatorial workrooms, light and heavy storage, compact shelving, interior landscaping with up to 4 ft equivalent of soil, open plazas with large stone sculptures, and outdoor areas with potential for emergency vehicle loading. As a result, there is a vast range of live loads within the museum, from basic office loading to H-20 truck loading in some outdoor areas over the moat.

The majority of the museum is gallery space, and a great deal of design effort went into studying gallery loading. The museum's curatorial staff provided the sizes and weights of all large objects in their collection and layouts for potential placement in galleries. Framing was designed to support sculpture point loads as large as 10,000 lb in various layouts. Floors were also checked for forklift loading during art installation and for scissor lift loading during maintenance.

The floors were also checked using the vibration standards in *AISC Design Guide 11: Floor Vibrations Due to Human Activity* for human perceptibility, and stringent deflection limits and curvature requirements were established for concrete creep in the composite deck flooring in areas with heavy long-term live loads.

Seismic Isolation

Rutherford & Chekene considered about 20 different potential isolation systems and properties during design. The selected system is comprised of 76 high-damped rubber elastomeric bearings by Bridgestone Rubber of Japan, 76 special flat sliding bearings made by Earthquake Protection Systems (like a flat friction pendulum bearing) of California, and 24 nonlinear fluid viscous dampers by Taylor Devices of New York. This system had the lowest base shear, lowest floor accelerations, and the lowest cost of those evaluated.

A complete set of bounding analyses using lower-bound and upper-bound isolation system properties was used throughout the design. Developed specifically for the project, the methodology was based on the lambda-factor provisions of the 2000 AASHTO *Guide Specifications for Seismic Isolation Design*. In addition to the seven project-specific time histories, actual near field records showing high energy in the long period range were used as a secondary check. The lower bound system period is

3.4 seconds, and the upper bound system period is 2.4 seconds.

The upper bound runs produce the highest forces. They use the upper end of the manufacturing tolerance range for stiffness and frictional coefficients, scragging recovery and the first cycle stiffness for the rubber bearings, and aging effects to account for rubber stiffening and some sliding bearing corrosion over time. The 0.38 g time history mean floor acceleration is well below the 0.5 g criterion.

The lower bound runs produce the largest displacements. They come from assuming the low end of the manufacturing tolerance range, the third cycle (scragged) stiffness for the rubber bearings and no aging effects. The 36 in. moat around the structure provides sufficient clearance for all of the worst records and gives a substantial cushion on the time history mean corner displacement of 26 in.

The roof of the main building undulates to simulate the park sand dunes and forest canopy. Herzog & de Meuron considered the copper roof to be the "fifth façade" since it can be seen from the upper levels of the tower. As a result, no mechanical or electrical equipment could be placed on the roof. Units were instead placed in the basement. The isolation crawl space was deepened to permit mechanical duct primary distribution. This triggered special details for the connection of the isolation system to the superstructure and extensive structural and mechanical coordination.

Tower

At the northeast corner of the site, a unique twisting tower rises up above the adjacent museum building and the forest canopy of the park. The tower rotates 30 degrees in plan as it rises, with rectangular floors of 38 ft by 90 ft at the base turning into parallelograms above. It is a fixed base building and seismically separated from the main museum building. While it is primarily an architecturally exposed concrete structure, it has an unusual steel-framed roof, and the perforated copper cladding is supported by steel pipe backup framing.

The top level of the tower is an observation level open to the public with continuous glazing on all sides, providing great views of western San Francisco and the Golden Gate. To keep all supports away from the viewing area at the windows, steel roof framing cantilevers out to the perimeter horizontally and then down from the roof level to the top of the window heads.

For the copper cladding, façade contractor A. Zahner Company and their structural engineer, Wallace Engineering, designed a steel pipe backup support system. It had to accommodate the twisting floors which cause the cladding to warp in three-dimensions, wind loads coming from the Pacific Ocean, live load deflections, and interstory earthquake drift in both the in-plane and out-of-plane directions. An elegant combination of both telescoping and swivel joints within the back-up steel framing allows for the necessary rotations and deflections.

A Must-See Destination

With spectacular views from the tower's observation level, distinctive architecture, and diverse permanent and traveling art exhibitions, the newly reopened de Young Museum has become a must-see destination for art and architecture lovers. MSC

Owner
Corporation of the Fine Arts Museums of San Francisco

Primary Designers
Herzog & de Meuron Architekten AG, Basel, Switzerland

Principal Architects
Fong and Chan Architects, San Francisco

Structural, Civil and Geotechnical Engineer
Rutherford & Chekene, San Francisco

Mechanical, Electrical and Plumbing Engineer
Arup, San Francisco

General Contractor
Swinerton Builders, San Francisco

Structural Steel Fabricator and Erector
The Herrick Corporation, Pleasanton, Calif. (AISC member)

Façade Contractor
A. Zahner Company, Kansas City, Mo.

Miscellaneous Metals
Romak Iron Works, Benicia, Calif.

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