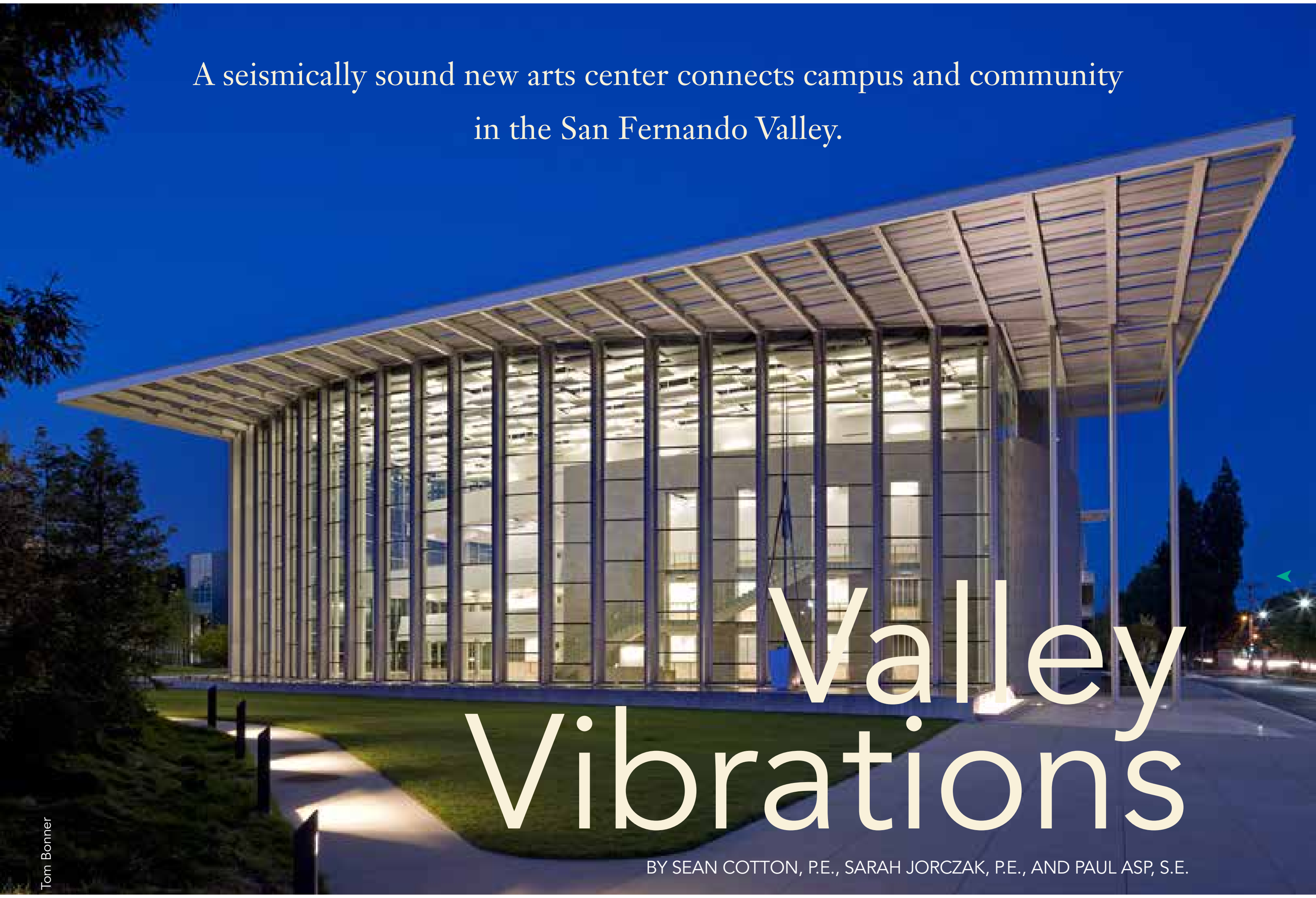


A seismically sound new arts center connects campus and community in the San Fernando Valley.

Valley Vibrations

BY SEAN COTTON, P.E., SARAH JORCZAK, P.E., AND PAUL ASP, S.E.

Tom Bonner

A 55-ft tall glass curtainwall reveals the interior of the Grand Lobby.

FOR NEARLY TWO DECADES, Northridge has been known as the center of the 1994 earthquake of the same name.

But as of last year, it has become an epicenter of the arts with the opening of the Valley Performing Arts Center (VPAC). Located on the California State University, Northridge campus, VPAC brings a world-class performance hall to the San Fernando Valley north of Los Angeles and creates a dramatic, inviting gateway between the school and the community.

Designed by HGA Architects and Engineers, the $98 million, 166,000-sq.-ft facility features a 1,700-seat public performance hall as its centerpiece. The Great Hall is designed as an acoustically superior, flexible performance space, accommodating symphonic orchestra, theater, musical performance, dance, opera, lecture and film. The VPAC complex, part of the university's Mike Curb College of Arts, Media and Communication, also includes a 178-seat flexible "black box" theater, the campus radio station, a 230-seat lecture hall and rehearsal, educational and performance support spaces.

The Great Hall features a 58-ft by 120-ft sprung floor stage with 55-ft-wide proscenium opening. It is supported by

Sean Cotton (scotton@hga.com) is an associate vice president in the structural engineering group, **Sarah Jorczak** (sjorczak@hga.com) is a senior associate in the structural engineering group and **Paul Asp** (pasp@hga.com) is vice president and director of structural engineering, all at HGA Architects and Engineers.

Lee Choo, Courtesy of California State University, Northridge

The lobby roof was framed on an 8-ft module, allowing columns to support both the roof and curtainwall.

a full fly tower and gridiron with 60 line sets for rigging, accommodating a wide range of performance types. The acoustics of the Great Hall are tuned by deploying a variable system of concealed draperies throughout the walls and ceiling of the hall, maintaining the aesthetic of the space in any acoustic environment.

The VPAC design team was challenged by the high seismic demands of southern California coupled with the irregular geometry of the performance hall. Design elements such as large cantilevered roofs, tall glass walls and tiered seating balconies added further complexity to the structural design.

Structural Framing Systems

Both steel and concrete systems were evaluated for the performance hall structure. To accurately compare costs, both systems were evaluated with finishes providing the same level of required acoustic performance. The evaluation revealed comparable superstructure costs. However, the large mass of a concrete system would have increased seismic forces and penalized the foundations, and a steel-framed solution was therefore chosen.

The typical gravity framing system consists of composite beams with lightweight concrete on composite metal deck. In most areas, 3½ in. of concrete on 3-in.-deep deck was used, spanning 8 ft to 10 ft. Due to seating geometry in the Great Hall, floor-to-floor heights as low as 10 ft occur at lobby spaces outside of the parterre and lower balcony seating levels. To minimize structural depth at these floors, W10 purlins were framed to W14 girders upturned to the top of the deck. This resulted in a nearly uniform elevation to the bottom of the structure and limited the total structural depth to approximately 18 in. Side wall HVAC distribution was used, and beam penetrations for fire protection piping were provided to maximize ceiling height in these lobby spaces.

The roof of the audience chamber is supported by steel trusses spanning 78 ft to 95 ft, spaced at 24 ft on center. The roof slab is 7½ in. of normal weight concrete on 3-in. composite steel deck, spanning to purlins at 8 ft on center.

Seismic Design

With the VPAC located in the heart of Northridge, Calif.—site of the 1994 Northridge earthquake—a primary focus of the structural team was the design of the seismic load resisting system (SLRS). At the time of design, the governing code in California was the 2001 California Building Code (CBC), based on the 1997 Uniform Building Code. As most states had adopted International Building Code (IBC) standards, the design team and owner felt it prudent to consider the most current code developments for design of the VPAC, particularly in the areas of seis-

Lee Choo, Courtesy of California State University, Northridge

Seating balcony risers were cast on permanent steel-framed formwork, eliminating the need for temporary concrete forming and shoring.

Special concentric braced frames were utilized at all four sides of the stage house to provide a stiff central bracing core.

AirPix West, Courtesy of California State University, Northridge

AirPix West, Courtesy of California State University, Northridge

The roof of the audience chamber is supported by four steel trusses spanning 78 ft to 95 ft.

mic design and detailing. To that end, the project was designed to IBC seismic force requirements, ensuring the design met the intent and minimum requirements of the governing building code, while providing a more robust structure. The SLRS was detailed per the requirements of the 2005 AISC *Seismic Provisions*.

Special concentric braced frames were used for the primary lateral load resisting system. Square tube sections ranging from HSS6×6 to HSS12×12 were used for braces and beam stub/gusset plate assemblies were shop-welded to columns, where practical, to reduce field welding at braced frames. This system was chosen to provide the necessary strength and ductility for major seismic events, as well as sufficient stiffness at service-level wind loading to protect the exterior stone tile cladding. Use of the IBC for seismic forces resulted in base shears that were approximately 33% higher than would have been required by the 2001 CBC for a similar concentrically braced frame system.

Complicating design of the SLRS was the irregular geometry of the project's centerpiece. The VPAC is composed of three seismically separated structures: the Great Hall, the black box theater building and the lecture hall and radio station building. The latter two buildings are fairly standard in terms of geometry. However, radial grids, large diaphragm discontinuities, stepped balcony seating and tall, unbraced walls combined to create a design challenge for the Great Hall.

Luckily, the Great Hall's four-sided stage house "box" and back wall of the audience chamber provided ideal locations for primary braced frame locations. Additional braced bays in the side walls of the performance hall and periphery of the back-of-house spaces were used to complete the bracing layout. While the stage house walls provided ideal bracing locations, the tall fly tower and adjacent horseshoe-shaped lobby and audience chamber resulted in large diaphragm discontinuities at the elevated seating levels. A study of diaphragm behavior determined that the lobby and back-of-house spaces at a given level responded to loading as two separate rigid diaphragms relative to the stiff stage house bracing core.

The irregular geometry and large diaphragm openings resulted in many highly-loaded chord and collector elements. Typically, single-plate connections were used for gravity framing and members with low axial collector forces. As collector forces increased, a series of progressively higher capacity connections were used, including multiple-row bolted single plates, bolted flange plates and fully welded moment connections for the largest forces. The largest ultimate collector design force was approximately 950 kips.

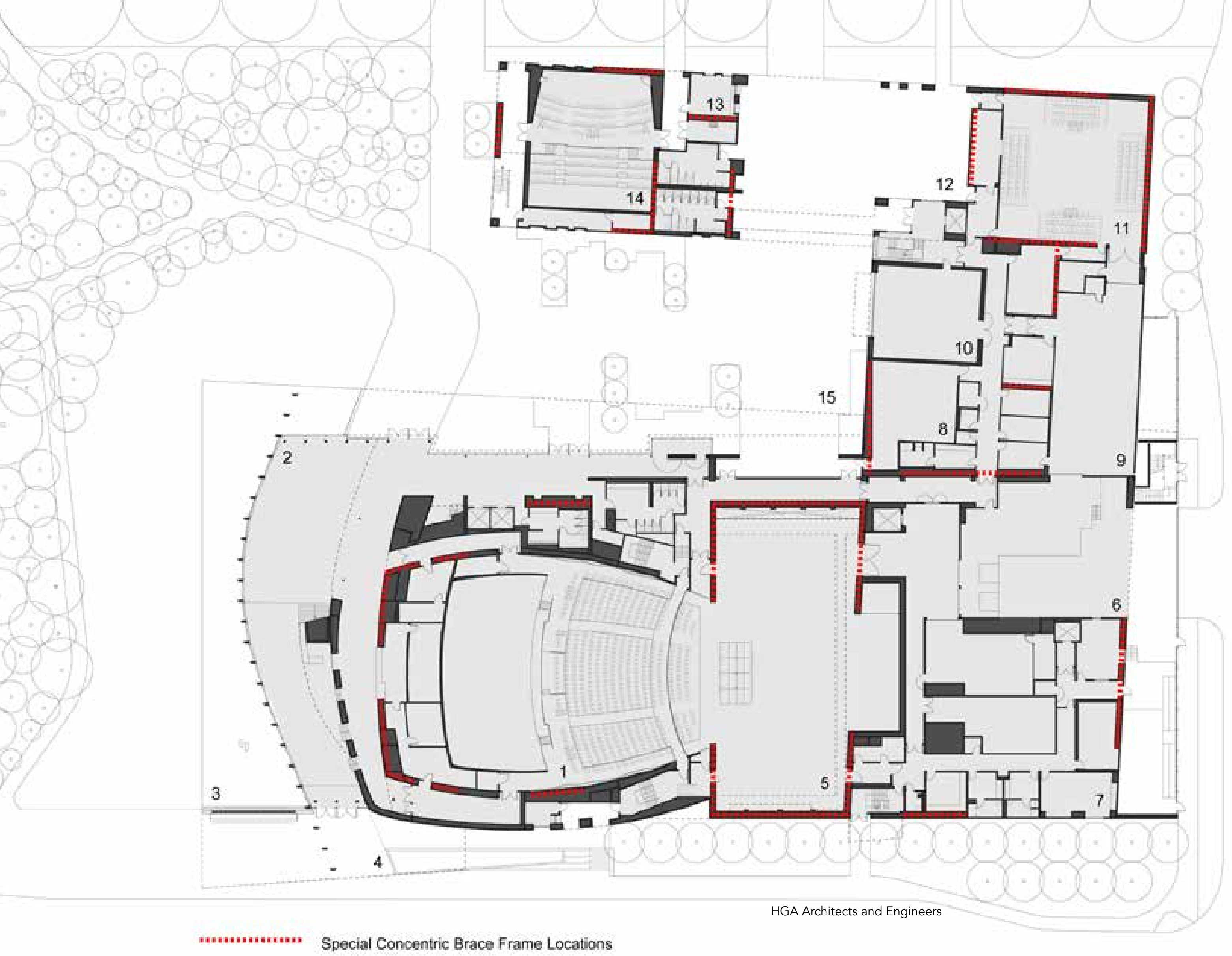
Grand Lobby

Welcoming students and visitors to the Great Hall is a striking 55-ft-tall curved glass curtain wall façade, revealing the multi-level grand lobby inside. The lobby roof cantilevers beyond the curtain wall, creating a linear edge above the curved glass and providing shading of the west-facing lobby with an open structure of perforated metal panels. The design team was challenged to design a large cantilevered roof while maximizing transparency of the glass façade below—at a glass wall budget comparable to standard curtain wall.

The solution was to design columns to support both roof and curtain wall. Each W24 roof beam is supported by an

▼ Bracing in the 88-ft-tall stage house side walls.

HGA Architects and Engineers



HGA Architects and Engineers

Building and site plan showing SLRS braced frame locations.

1	Great Hall
2	Lobby
3	Reflecting Pool
4	Entry Drop-off
5	Stage
6	Loading
7	Back-of-House Support
8	Lighting Lab
9	Scene Shop
10	Rehearsal Room
11	Experimental Theatre
12	Covered Exterior Lobby
13	Box Office
14	Lecture Hall
15	Courtyard

HSS18×6 column on an 8-ft module spanning 55 ft in enclosures between curtain wall mullions. Rectangular sections were used to minimize the width of the enclosures parallel to the glass and provide sufficient stiffness for out-of-plane wind and seismic loads. Column slenderness was controlled by post-tensioning the anchor rods, providing partial fixity at the column bases. The south end of the lobby roof features the longest cantilever at just over 50 ft. Beam sizes up to W24×229 were used to satisfy deflection requirements at these locations.

Due to significant dead load deflections of the longest cantilevers, upward tip cambers were required at many beams to provide a flat roof when erected. Additionally, cantilever and backspan lengths varied for each beam, resulting in a large number of unique beam camber requirements. Working with the contractor and erector to establish the erection sequence and temporary shoring requirements, the team was able to more accurately calculate the expected deflections at the time of erection. Final camber tolerances were controlled by adjusting baseplate elevation using the anchor rods. The result is a sharp, thin roof edge that draws focus to the grand lobby.

Seating Balconies

The Great Hall features two levels of balcony seating with superb sightlines. Balcony trusses at the rear of the audience chamber are constructed from W12 shapes with flange-bolted gusset plates, and cantilever up to 20 ft. Each rear balcony is supported by four parallel trusses spaced 16 ft to 24 ft. The lower balcony trusses act as transfer girders, transferring column loads from upper balcony supports to offset columns below the lower balcony. Curved concrete seating risers were cast on the trusses using a permanent formwork of radiused steel angles, vertical plates and horizontal steel deck, eliminating the need for a costly temporary forming system.

Limiting vibration due to lively audience participation was a governing consideration for the balcony trusses. Vibration concerns were mitigated by controlling midspan balcony edge deflection between seating trusses, thereby increasing the natural frequency of the framing. Cantilever tip deflection was reduced by adding a secondary truss system comprised of back-to-back L8×8 angles. The secondary truss was placed horizontally and perpendicular to the top chord of the seating trusses. Evaluation of balcony vibration was in accordance with AISC Design Guide 11: *Floor Vibrations Due to Human Activity*. The design guide criteria, extrapolated to balcony structures, limited the maximum recommended acceleration due to rhythmic activity to 5% of gravity and required a natural frequency higher than 4.5Hz. Modeling of the balconies for vibration analysis included effects of column stiffness and truss interaction to ensure all significant contributions to the system's natural frequency were captured.

In addition to supporting balcony seating, the trusses also act as distribution plenums for a displacement ventilation system at the balconies. Air is delivered to the plenums from basement mechanical spaces via a system of tunnels under the main level seating floor. Computational fluid dynamics (CFD) models were used to design the balcony ventilation system, and the HGA mechanical and structural teams ensured the structural geometry was accurately represented in the balcony CFD models. The efficiency of the resulting displacement ventilation system helped earn the project LEED Gold certification by the USGBC.

In its first year, the Valley Performing Arts Center has become a major regional destination and transformed the arts landscape in the San Fernando Valley. Aided by an elegant and innovative use of structural steel, the CSUN campus and greater community now enjoy a new architectural landmark and world-class performance venue. MSC


Tom Bonner

▲ Interior of the performance hall as seen from the stage.

▼ The interior of the Great Hall features curved wood veneer panels concealing catwalks and variable acoustic systems.


Tom Bonner

Owner
California State University, Northridge

Architect and Structural Engineer
HGA Architects and Engineers, Minneapolis

Construction Manager
C.W. Driver, Pasadena, Calif.