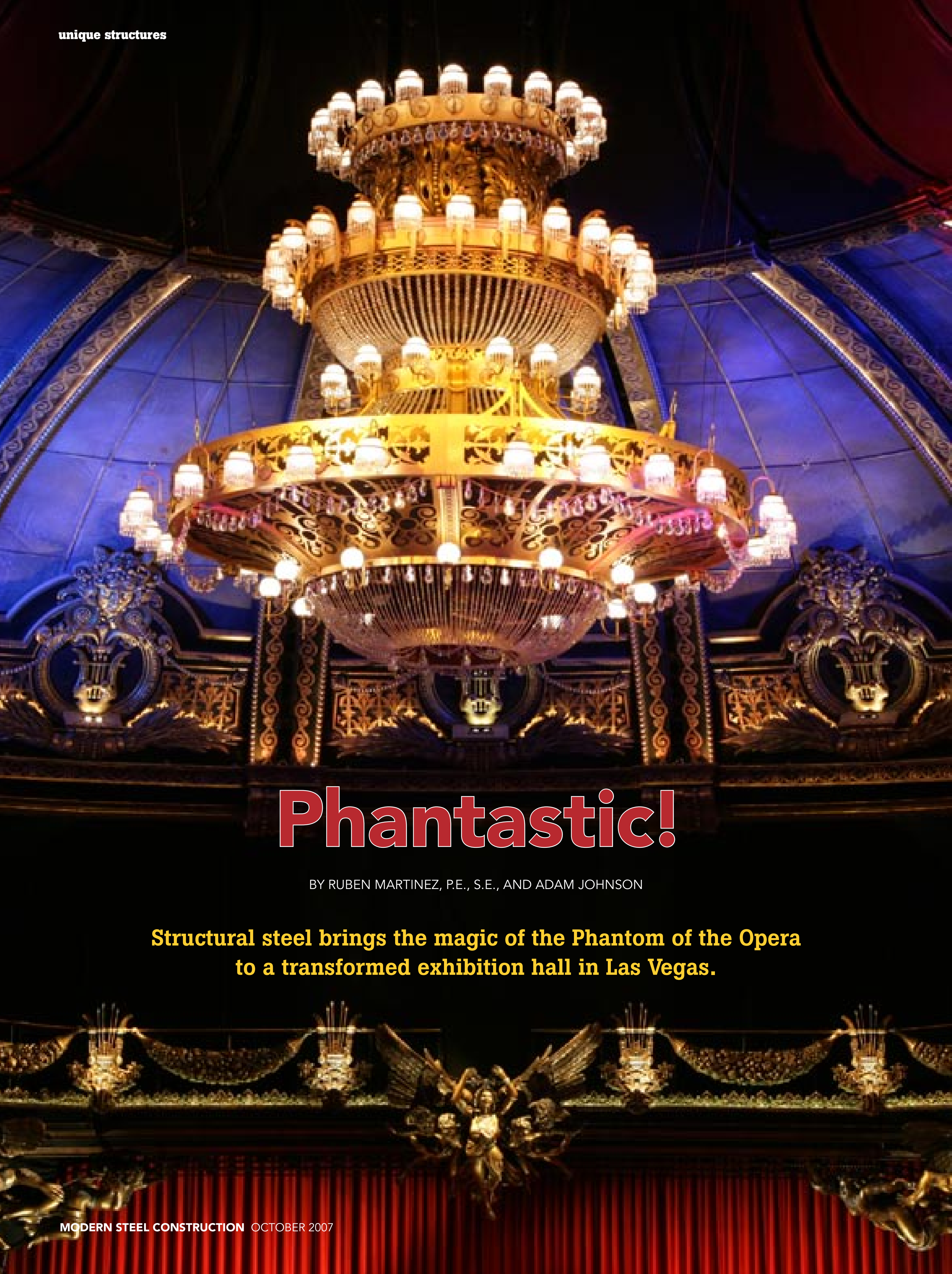


Phantastic!

BY RUBEN MARTINEZ, P.E., S.E., AND ADAM JOHNSON

Structural steel brings the magic of the Phantom of the Opera to a transformed exhibition hall in Las Vegas.

"PHANTOM—THE LAS VEGAS SPECTACULAR," A RECREATION OF THE FAMED MUSICAL "THE PHANTOM OF THE OPERA," RECENTLY OPENED TO RAVE REVIEWS AND SOLD-OUT CROWDS AT THE VENETIAN RESORT HOTEL CASINO. The lavish $40-million, 1,800-seat Phantom Theatre is the result of painstakingly tailored design and use of structural steel to transform an existing exhibition hall into the show's Paris Opera House setting.

The outcome is magnificent—beautiful finishes, an impressive domed ceiling, and thrilling performances and special effects, particularly an operable 2,100-lb Baroque-style chandelier that transforms from a dilapidated state back to its original grandeur while gliding up to the ceiling.

Scene 1: Laying the Foundation

Micropiles were the foundation system best suited for the constrained project site that offered limited access for construction equipment. Grouted shafts were drilled up to 75 ft deep. Under steel columns, pile caps utilized groups of three or four micropiles. The tops of the micropiles—which were designed to carry downward forces as well as uplift and lateral seismic forces—were simply cast into the walls to support the heavy loads from the concrete stage house. Using a smaller-than-typical drill rig, the design team placed column foundations and walls in very the tight spaces created by the existing structure and its neighbors.

Scene 2: Stage House Box

Most of this spectacle's magic happens in the stage house. At the east end of the theater, the massive concrete stage house is 125 ft long by 45ft wide by 112 ft tall. At the front of the stage house is the 55-ft-wide by 35-ft-tall plenum that opens to the theater and through which the audience watches the show. At the roof level, the 18-in.-thick concrete walls support steel roof framing, which in turn supports an intricate system of pulleys capable of flying over 80 tons of scenery.

To resist the large downward and lateral forces imparted by the pulleys at the counterbalance point, a built-up steel beam—consisting of a W36×230 stiffened by a horizontal W36×160 welded to the web and stiffened with ⅝-in. plates—was required. A steel gridiron hangs from the roof steel and provides the crew's platform, almost 80 ft above the stage. Below the gridiron are two more intermediate fly gallery platforms from which smaller scenery pieces can be hung. At the stage level, new openings were cut in the existing concrete floor to accommodate temporary floors supported at the basement slab below.

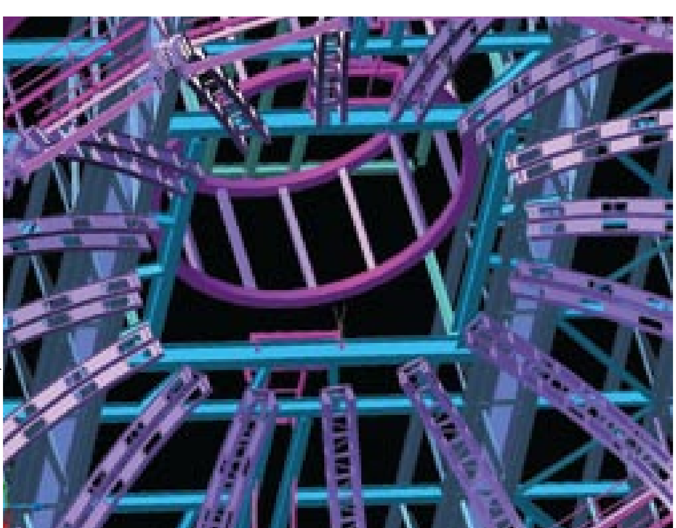
Backstage, the new stage house had to coexist with and incorporate the neighboring structure. The existing Guggenheim Hermitage Museum used a 59-ft-wide by 69-ft-tall steel-framed "megadoor." To save demolition costs, the design team moved the door to the open position and locked it permanently into place, where it serves as the exterior wall for the loading dock. The 36-in. pipe column that served as the hinge for the door was filled with concrete and incorporated into the stage house wall.

Scene 3: From Museum to Theater

Some interesting transformations were required to nest the intricately decorated theater within the confines of the existing structure, which had a heavy concrete structure for the exhibit floor that withstood live loads of 250 psf. This structure would have definitely been able to support a theater usage—if not for a 32-ft-wide trench right down the middle! The beams at the trench edge came equipped with continuous steel embeds that previously supported a removable floor that spanned from one side to the other. The existing embeds were used to weld connections for new (and permanent) composite steel beams that would close the trench for good and provide a continuous structure to support the Orchestra seating above.

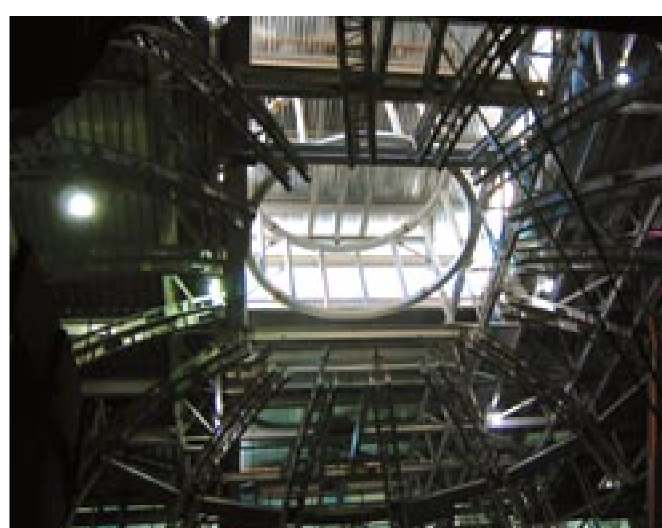
At the rear entrance to the theater, the elevated Parterre lobby is comprised of composite beams framing into wide-flange steel columns. The theater's stepped seating area is framed with composite beams supported by concrete walls that rest on the existing floor below. The seating area floor system consists of a minimum 2½ in of normal-weight concrete over 1½ in composite steel deck.

Column-free viewing and vibration control were important considerations for patron enjoyment. Patrons seated at the Balcony Level arrive via the Grand Stair from the level below. The



Fisher Technical Services, Inc.

3D rendering of steel structure supporting the Phantom chandelier (including tracks, winches, and equipment).



Walter P Moore

Construction photo of the intricate structural steel backbone of the ornate theater ceiling.

elevated Balcony Level is supported primarily by built-up steel plate girders that provide column-free views for the patrons below. The plate girders had to cantilever the required 23 ft and provide enough stiffness to control objectionable vibrations to balcony patrons, and be shallow enough to not affect the view from the Parterre below. To accomplish these goals, the plate girders taper from 42 in. deep at the supports to a slim 8 in. at the cantilever tip.

The theater is laterally stabilized by four braced frames that were strategically located by the design team so as to not obstruct any views, while also providing the necessary resistance in the event of an earthquake. With the site falling under Seismic Design Category C, according to IBC 2000, ordinary steel concentrically braced fames provided an economical solution. The braced frames consisted of wide-flange columns and beams with either double-angle or rectangular HSS diagonal members.

Scene 4: A Supportive Ceiling

Like any theater production, Phantom requires numerous catwalks and equipment rooms above the theater from which technicians control lighting and other operations. For this production, however, the designers also envisioned an intricate dome ceiling that houses a 2,100-lb mechanized chandelier that can move about the theater. But, the existing roof structure did not have the capacity to support such a structure. To solve this challenge, the design team devised a long-span solution to take advantage of the museum's crane rails, which were supported by beams 125 ft apart. The design team utilized four steel box trusses supported by posts from the crane rail support beams. The box truss was necessary for stability because the top chord would not be braced by the roof or ceiling structure.

The steel fabricator was involved early in the design phase in order to provide the most structurally efficient and economical trusses possible. The fabricator constructed the trusses on the ground and lifted the whole truss into place, and also welded all of the connections—a situation that lent itself well to the configuration that was ultimately chosen. The chords were web-vertical W14 shapes while the web members consisted of double-angle tension diagonals and HSS compression posts forming panel points at approximately every 12 ft. The web-vertical bottom chords allowed for standard shear connections for the supported ceiling beams and flexibility in the location of these beams without subjecting the chords to minor-axis bending. The two faces of each box were then connected at the top and bottom chords with double-angle laces and battens.

Scene 5: The Chandelier's Big Scene

Exactly how do you support a chandelier that designers described as "exploding" and is so integral that it is thought of as a main character? Early design discussions included a turntable structure, a chandelier that broke into several pieces, and a chandelier that needed to move from its static position at the center of the domed ceiling to the stage itself—with the Phantom in it! Again, structural steel proved to be the answer.

The mechanized chandelier is introduced to the audience in a grand fashion. The production begins as a dilapidated chandelier ascends from the stage toward three other pieces of chandelier and reassembles before gracefully rising to its static position in the theater ceiling. Later in the show (and to the surprise of those sitting close to the stage), the Phantom and the chandelier descend from the ceiling. Then, in a flash, the chandelier rises back up to its at-rest position.

Design requirements for the chandelier were coordinated between the structural engineer and a specialty contractor; these included the weight allowances for the chandelier, the tracks, and the various winches required. In order to support the tracks on which the chandelier traveled, 16 curved "pocket beams" were designed using two W21x50 beams with detailed web openings and laced together at the top. The bottom flanges could not be laced, as this would have literally stopped the chandelier in its tracks and prevented the travel of the cables and ultimately the chandelier. The curved pocket beams were in turn supported by the ceiling structure (steel beams and box trusses). Because the chandelier was from the onset conceived to travel in pieces and throughout most of the ceiling space, the engineer had to model, analyze, and design for the chandelier weights at various different locations within the ceiling. This in turn gave the chandelier's specialty contractor a great deal of flexibility in tailoring its path in the show.

Music of the Night

If and when you ever find yourself in this Las Vegas theater waiting for the Phantom overture to begin, take a few moments to admire the building's magnificent structure and intricate interior. A "phantastic" performance by the design team will take you back to the Paris Opera House in all its splendor. On with the show! MSC

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Engineering Software
SAP2000 and ETABS