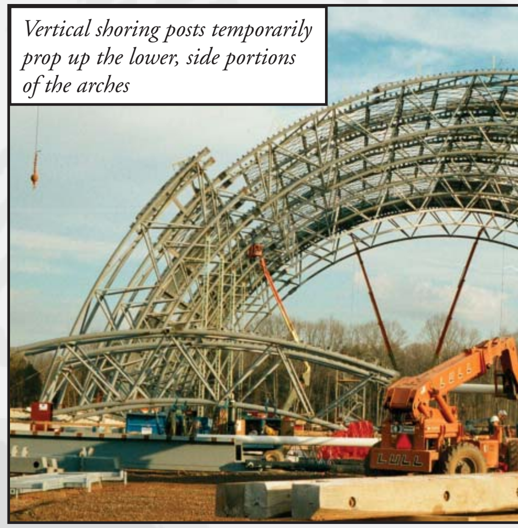
America's Showcase Hangar

Steven F. Udvar-Hazy Center

By Satish Shah, David Oleynik and James Whynot

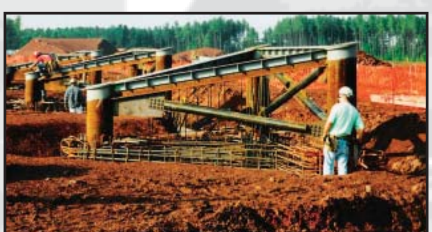


Vertical shoring posts temporarily prop up the lower, side portions of the arches

The Smithsonian's new National Air and Space Museum Steven F. Udvar-Hazy Center located at Dulles Airport in Chantilly, Virginia, houses a collection of hundreds of aircraft and related artifacts. Some of the exhibits in this larger than life facility, affectionately dubbed 'America's Hangar' by the museum staff, include the Space Shuttle Enterprise, the SR-71 Black Bird, an Air France Concorde, the B-29 Superfortress Enola Gay, a Boeing S-307 Stratoliner and many others.

During the pre-schematic planning sessions the tremendous scope of this project immediately became evident, with at least six or more major interconnected structures. The main hangar and its side galleries are the centerpiece of the facility, enclosing an enormous exhibit hall of more than six acres (about 2.4 ha for those fluent in metric).

Other components include another large adjoining hall called the space hangar, dedicated to space exploration, adding an additional acre of exhibit space, a 47.5m (150-foot) tall air traffic control tower (exhibit), a 450 seat IMAX theater with rooftop restaurant and conference center, entry and administration wings with offices, classrooms, food court, museum shop, etc., and the central utility plant building.



The truss base subframes have a 500 mm (20 in.) diameter vertical pipe column below each arch chord member. They are adjusted to final position and placement of cap reinforcement begins.

Designed, but not yet built, are a large restoration hangar and an archive facility. Together they will add another 235,000 square-foot (about 2.2 ha) of space to the current facility.

The cost of construction was funded entirely from donations. The tension between the needed flexibility of the program requirements and the budget constraints required everyone involved, including Smithsonian's exhibit planners and the design consultants, to think creatively. During the master planning phase various forms, shapes and materials were considered to arrive at suitable solutions.

The completed foundation block stands ready for erection of the arch truss. The architecturally exposed upper portions of these concrete bases are a visual feature in the main hangar.

Spiegel Zamecnik & Shah Inc. studied various structural systems and the estimated unit costs of various building shapes and materials to create column free spaces with spans ranging from 50m to 120m (160 to 400 feet). Also included in the study were proprietary systems. The architect added costs for roofing and perimeter enclosure for each system that together resulted in a comparison of total unit costs for the range of spans and systems under consideration.

Based on various factors, including cost, the finished space and use, a design featuring three dimensional arch trusses with an overall width of 74m (243 feet) and a crown height of 31m (102 feet) was selected for the main hangar. With a truss spacing of 15m (50 feet) the total length of the main hangar's roof is over 305m (1,000 feet).

The site assembled center portions are craned into position completing the arch. Additional assembled lower, side portions which have not yet been raised are visible in the foreground on either side of the crane.

The trusses are triangular in cross section, having a pair of top chords 5m (17 feet) apart and a single bottom chord 4m (13 feet) radially below the top chords. Chords are all nominal 300mm (12-inch) diameter steel pipe with varying wall thickness. The web diagonals are 125mm and 150mm (5- and 6-inch) pipe. Each truss is designed for various combinations of roof dead loads, balanced and unbalanced snow and wind loads, hanging artifacts of up to 9000 kg (20 kips) per truss, and hanging walkway mezzanines 3m (10 feet) wide. There were over two hundred load combinations, with a few dozen combinations being critical.

All three chords of each truss continue to the base and connect to the concrete foundation block. This type of base connection (which is different from that of a typical hinged arch) provides additional stiffness for the roof to control deformations under various loads. It was critical to minimize the roof movements, as planes and other artifacts hang from the trusses.

Between the trusses, open web steel joists support an acoustic roof deck. Acoustic deck was chosen to minimize the effects of sounds echoing back to the hangar floor and creating a noisy environment.

The arch bases consist of (3) 1070mm (42-inch) diameter caissons socketed 1.2m to 2.4m (4 to 8 feet) into decomposed or solid rock. Reinforced caissons are tied to a large reinforced cap, creating a moment frame resisting the lateral and vertical reactions from the steel arches. A structural steel subframe was encased in each cap to allow precise field adjustment of the arch truss to foundation connection.

At each end of the main hangar is a large two leaf canopy door with an opening of 45m (150 feet) by 12m (40 feet) to allow for transportation of the artifacts into the hangar. The structure for the end wall over the doors is a vertical steel truss spanning between buttressed column frames flanking the door. The curved top chord is independent of the endmost arch truss for in-plane movements. It is detailed to receive support and bracing from the arch to resist out-of-plane loads. Lateral forces collected at the top of door opening are resisted by a horizontal truss spanning between the buttressed columns, which are cantilevered from their caisson foundations.

The segmented top chord of the vertical truss, spanning across the canopy door opening, follows the curving bottom chord member of the endmost arch truss. The x-braced, buttressed columns flanking the opening, support the vertical truss and the door and house the door's counterweights.

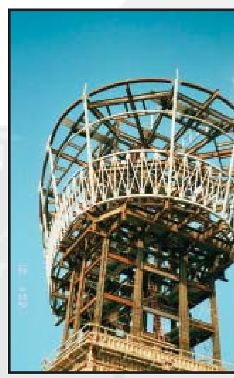
Arch truss web-to-chord connections were originally designed as fitted, 'gap K' type welded connections as an architectural feature. The Canadian Institute of Steel Construction (CISG) recommendations were used as a design guideline since it was prior to the publication of the AISC 'Hollow Structural Sections' manual. A fabricator initiated value-engineering proposal resulted in a change to the transverse gusset plates shown here. The re-design, took place during the shop drawing phase. It required addressing each of the many web-to-chord member size/wall thickness combinations, in a timely fashion, to arrive at the proper connection geometry for each variation.

The space hangar is a 45m (150 feet) wide and 80m (260 feet) long exhibit space adjoining the west side of the main hangar at the north end. Its superstructure is a three dimensional proprietary design space frame. It houses the space shuttle Enterprise, along with other smaller rocket and space exploration exhibits. The frame is designed to support up to 2,300 kg (5 kips) of hanging load from any of its bottom nodes.

At the west end of this hangar there is a large six leaf parting/sliding door with a maximum opening of 30m (100 feet) wide and 12m (40 feet) tall. The opening width is sufficient to allow passage of the shuttle, except for its tail. The structure at the end wall is designed so that the center portion can be removed when the doors are fully open to allow the shuttle with its tail to pass through.

The museum entrance, mimicking the curbside feel of an airport, features a glass roofed porte-cochere, an extensive, cantilevering bus canopy, and monumental atrium and the control tower.

The floor of the main hangar is designed to support up to 21,200kg (46 kips) of concentrated load, the wheel load of the heaviest anticipated artifacts. The concrete slab thickness varies from 250mm to 325mm (10 to 13 inches), and is reinforced with steel fibers and a two directional mat of reinforcing bars to minimize cracking and to distribute concentrated loads. Similarly the 375mm (15 inch) thick floor of the Space Hangar is designed to support a concentrated load of 45,000 kg (100 kips). Light reflective dry shake hardener was used for uniform appearance and to resist surface deterioration under forklifts and other equipment that deliver, support, and set the artifacts. Embedded in the slab at 8m (25 foot) intervals are utility ducts for future communication and power connections as needed for the exhibits.



The 47.5m (150 ft.) tall control tower, which contains a large observation deck as well as the air traffic control exhibit, has a slender steel frame encased in concrete shear walls to control drift and vibration. The upper levels, egg shaped in plan, cantilever from the core.

The Smithsonian needed a building to showcase the many aircraft and other artifacts in their collection. The museum's main hangar accomplishes this from a functional aspect, but also architecturally, with its three-dimensional arch structure which is reminiscent of the dirigible hangars of times past.▪

This article was prepared by three members of the Spiegel Zamecnik & Shah Inc design team: James Whynot, senior engineer, David Oleynik, P.E. principal, and Satish Shah, P.E. senior principal. Spiegel Zamecnik & Shah Inc, has offices in Washington, DC and New Haven, CT. They can be reached at ***engineers@szsdc.com***

All photos courtesy of James Whynot/SZS