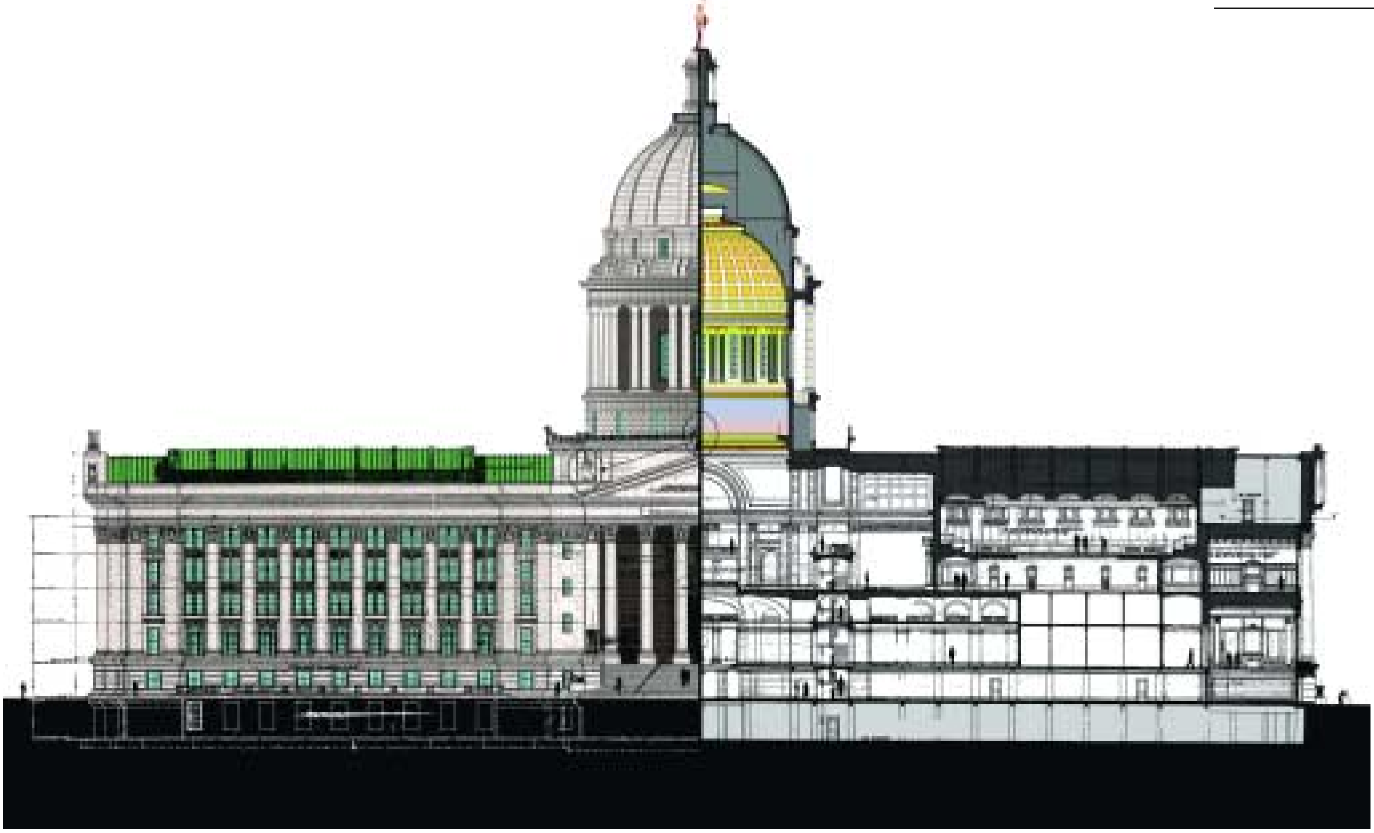
Capitol Improvements

By Gene O. Brown, P.E. and Timothy J. Dolf, P.E.



Graphic courtesy Frankfurt-Short-Bruza.

A design-build effort topped off Oklahoma's nearly 90-year-old State Capitol building with a crown of steel.

In late 2000, the Oklahoma Department of Central Services developed a $21 million project to construct a new dome for the State Capitol building—the State's first, major design-build contract. Oklahoma's State Capitol originally was constructed between 1914 and 1917, northeast of downtown Oklahoma City. While original plans for the Capitol indicated a large dome, a small saucer dome was constructed instead, since, at the time, World War I efforts drew money, labor and materials from domestic projects. The saucer dome was intended to be temporary, but it remained for nearly 90 years.

For the new dome project, the Department of Central Services and the Oklahoma Historical Society wanted a structure that closely resembled the original plans and matched the existing weathered limestone. The Capitol had to remain fully operational during construction, and artwork located below the saucer dome had to be protected from construction activities and the weather. A design-build approach allowed team members to share their expertise early in the planning stages to identify construction sequences and methods that would accommodate the owner's requirements (see design-build sidebar on p. 33 for more). The construction schedule allowed six months for site investigation, architectural design and engineering, and 19 months for construction. The completion date was scheduled to fall on Statehood Day, November 16, 2002.

Structural Exploration

Prior to architectural design and engineering, the existing condition of the Capitol had to be verified. A thorough, in-depth review had never taken place, but The Oklahoma Historical Society had preserved the original project specifications, construction drawings (ink on linen), construction photographs and Capitol Commission meeting minutes. Among the original construction drawings were five architectural sheets and a single structural sheet depicting the originally planned large dome, even though it was never constructed.

A detailed structural exploration was conducted using this information. Existing framing members and structural systems were verified, core samples were taken and steel reinforcing bars were removed for testing. Core samples indicated consistent concrete compressive strengths of about 1,610 psi in the superstructure, and 3,270 psi in the foundations. Steel reinforcing bars varied from square, twisted square, deformed round and smooth round bars, and consistently indicated a yield strength of approximately 49,000 psi. The investigation confirmed that the original structure was constructed to support the large dome.

The general plan consisted of an 80′-diameter exterior dome rising 140′ high above the existing roof. The dome would be capped with a 17′-tall, 6,000-lb bronze statue entitled "The Guardian," and would house an inner, coffered dome of glass-fiber-reinforced plaster panels. Access would be provided to the base of the lantern atop the dome through a series of ship ladders, catwalks and spiral staircases.

Photo courtesy R. Greg Hursley Incorporated.

Photo courtesy Capitol Dome Builders.

The concrete ring-beam from the existing dome served as the base for the new structure's 48 columns. Anchor rods were field-located to avoid disturbing the existing rebar in the ring beam. The field-located anchorages required that each base plate be custom-fitted at each location.

Since the original structural system was a cast-in-place-concrete frame, project architect/engineer Frankfurt-Short-Bruza (FSB) first explored concrete options. However, FSB realized that the original structure could not accommodate the additional weight of a concrete dome and meet current building codes. A steel-framed solution wrapped in architectural pre-cast concrete and cast stone (to match the appearance of the adjacent weathered limestone) provided a building system that was 60% lighter. After demolition of the small saucer dome and construction of the new dome, the net increase in overall building weight was approximately three million pounds (4% of the overall building weight). Minimizing the additional weight was important since the existing structure did not meet current seismic detailing requirements, and was not believed to be capable of supporting design seismic loads.

A structural steel frame was affordable and readily available from local sources. Steel connections and splices primarily used tension-control bolts. The steel framing could be easily assembled in sections on the ground and then lifted into place by the largest, free-standing tower crane ever erected in Oklahoma—a Comedil CTT 561-20. The crane could reach 230′ away from its tower with a height of 270′ above the ground. During times of high wind (when the crane could not be used) assembly of steel sections on the ground allowed construction to progress.

Designing the Dome

To meet the original dome design, the architectural features and proportions dictated the configuration of the structural steel framing system. The exterior colonnade around the drum of the dome consists of 16 pairs of 12″-diameter standard pipe columns wrapped in pre-cast concrete. The interior drum of the dome consists of 16 W14x176 wide-flange columns vertically braced above and below tall, narrow windows. Above these columns, at the base of the exterior dome, is a concrete-on-steel-deck tension ring that supports a mechanical mezzanine and forms the oculus of the interior dome. From this tension ring, 16 arched W10x49 wide-flange sections form the dome and terminate at the compression ring near the base of the lantern. A 36″-diameter steel pipe with a large cap plate extends 30′ upward through the lantern to support the base of the statue. Including connections, the structural steel totaled approximately 250 tons.

The lateral-force-resisting systems varied, since moment frames, vertically braced frames and inverted pendulums were all used at different elevations. Due to architectural features, vertical bracing could not be used exclusively. The largest portion of the lateral drift occurs within the drum section where vertical bracing had to be discontinued at the tall, slender windows, which in effect created a series of vertical Vierendeel trusses. The total lateral design drift of the new dome was limited to its height divided by 300. The final structural models indicated that the dome's horizontal drift would be approximately 1.6″ under a design seismic event and 1.4″ under the design wind loads.

The new dome attached to an existing 5′-thick-by-9½′ wide concrete ring beam (100′ above the foundation/basement level) which was in turn supported by columns that formed the central core area of the Capitol. In order to preserve the strength and integrity of the concrete ring beam, care was taken to not damage any of the existing rebar. Workers determined each anchor-bolt location by locally chipping down to the top mat of reinforcement, then drilling small pilot holes to locate and avoid lower mats of reinforcement. The 48 columns each have a unique base plate since all 352 post-installed anchors were field-located to avoid the existing rebar.

Designers modeled the new structural steel framing atop the original central core area of the Capitol building and existing spread-footing foundation. They used three-dimensional structural modeling software, and due to the complexity of the construction sequencing, several models were required to analyze the structure. The computer models used a P-Delta analysis and were simplified by taking advantage of the inherent radial symmetry of the dome. The final structural model required 1,704 joints, 452 spring supports and 2,389 elements to model the existing foundation, existing concrete members and the new steel members.

Capitol Construction

Two temporary work platforms were incorporated into the dome design. The lower platform was located within the existing structure, on the fourth floor of the Capitol, to support interior demolition of the small saucer dome and later to support construction efforts on the interior of the dome. The upper platform attached to the new structure, creating a work-staging area. It also created a weather-tight enclosure with temporary walls, forming a white box that extended downward to seal off the opening in the Capitol's roof, 26′ below. This helped protect the original artwork and allowed the Capitol to remain operational during construction.

The radial beams of the platform projected through the 16 future window openings, and the columns extended

Why Choose Design-Build?

For the Oklahoma Capitol Dome, the design-build approach made sense due to the project's unknown conditions and the need to incorporate complex construction sequences into the design. Modern construction materials had to match the original materials—within budget, on a tight schedule and under intense scrutiny.

Capitol Dome Builders worked with FSB to develop construction sequencing and the concept of temporary, elevated work platforms. These platforms served as weather-tight enclosures and had to be incorporated into the structural design since they represented the largest load that the structure would experience. Had this been a traditional design-bid-build project, the design team might not have accounted for these work platforms, and the contractor would have had to stage all work on the ground, hundreds of feet below. While this would have made the structural component of the dome more economical, the contractor determined that additional materials were not as costly as the potential costs of additional time, money and labor.

Some other benefits of the design-build team:

- ➜ Team communication played a positive role in identifying potential complications and challenges before they became a construction problem.
- ➜ When unexpected field conditions were encountered, engineers arrived quickly on-site to help determine a solution.

Photo courtesy Capitol Dome Builders.

- ➜ Design-build contracts can offer a less adversarial relationship between contractors and engineers, since they are team members under the same contract. They allow direct communication between the engineers and contractors. For example, incorporating the elevated work (staging) platforms saved time and money by making construction/staging more convenient.
- ➜ Since the contractor was on-board and involved during design, early steel packages allowed construction to follow directly behind design without any delay. Site mobilization occurred prior to the completion of design. Steel shop drawings arrived just as 100% construction documents for other disciplines were completed.
- ➜ Being part of the design-build team meant FSB could aid in connection design, tower-crane foundation design, platform/scaffolding checks on the existing structure, and other tasks.
- ➜ FSB's involvement in connection design drastically reduced shop-drawing review time. ★

through the platform and were sealed. Hatches and a penthouse were constructed to allow workers, demolition debris and construction materials to pass back and forth through the weather-tight enclosure during construction. The top of the platform was approximately 12,000 sq. ft and could support a 50 psf live load. It was constructed with 2″ of polypropylene-fiber-reinforced concrete over a water-proofing membrane, over another 2″ of reinforced concrete. Scaffolding was erected from the perimeter of this platform as the exterior construction progressed. As the exterior of the dome neared completion, interior portions of the platform were removed so the interior dome could be constructed through the platform. When the exterior portion of the dome was completed and became weather-tight, the entire platform was removed through the window openings. This allowed interior construction to progress upward with a 140′-tall interior scaffolding system from the existing fourth floor below.

The governing gravity-load combination was anticipated to occur near the completion of exterior construction, when the building was complete and the platforms were still supporting 120,000 lb of scaffolding and other construction materials and debris. The design-build process helped the architect, engineer and contractor incorporate realistic construction loads and needs into the structural design—cutting the construction schedule and lowering the construction cost.

Since designing and constructing a dome on an existing Capitol had not been attempted in the United States since the U.S. Capitol in 1865, this was a once-in-a-lifetime project. Many Oklahomans watched in person or on live television as the dome was dedicated in an Oklahoma-themed show on Statehood Day, with the largest fireworks display in State history. ★

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Owner

The State of Oklahoma, Department of Central Services

Architect and Engineer of Record

Frankfurt-Short-Bruza Associates, P.C., Architects Engineers and Planners, Oklahoma City

Contractors

Capitol Dome Builders: (Manhattan Construction Company, Oklahoma City and Flintco Incorporated, Oklahoma City)

Structural Steel Fabricator

H&M Steel Corporation, Luther, OK (AISC member)

Detailing

Connection Design: Frankfurt-Short-Bruza Associates, P.C., Oklahoma City

Shop Drawings: H&M Steel Corporation, Luther, OK (AISC member)

Structural Software

STAAD.Pro