Home Court ADVANTAGE

David C. Douglass, Cary M. Andrews, P.E., and Beth S. Pollak

Teamwork was the key to a high-speed roof replacement at Clemson University's Littlejohn Coliseum.

Clemson University's Littlejohn Coliseum is known as one of the toughest stadiums for a visiting team to play in college basketball. Clemson fans sit near the court and lend support to their team at every home game. In spring 2002, the 34-year old stadium was in the midst of a renovation when it was discovered that the roof was damaged to the point that it could no longer function safely. Confronted with an enormous challenge to solve before the next basketball season, a team of engineers, fabricators, and erectors removed the stadium's roof and replaced it with a new one—in a process that took, in total, just over three months.

ROOF REPLACEMENT

Clemson officials had planned the original renovation of Littlejohn Coliseum in August 2001 to add fan amenities, update architectural features, increase practice courts and enhance the capacity of the roof for show rigging. In 2001 renovations began as South Carolina Steel Corporation was contracted with Beers Skanska (then Beers-York) to construct the annex portion of the stadium and the three entrance foyers. However, during the later stages of the work, critical structural problems in the roof were discovered.

The roof problems were a case of application outpacing technology. The original design, detailing, fabrication and erection of the existing roof did not have the benefit of what is now well-known about such factors as bi-axial stress, residual stress, welding sequence and preheat.

"We had a decision to make—a perplexing one," said project architect Mike Keeshen. "Continue as we were, and end up with a bad roof? No way. We had to fix it."

Construction of an entirely new facility was not considered a viable op-

Opposite page: An aerial view of the last of the 120' truss sections being put in place.

Left: View of the 60' truss sections in the shop after assembly and painting. The ends are unpainted for the slip-critical bolted field splice.

Below: View from inside the arena looking up after the roof deck was installed. Note the "built-in" catwalk system. The joists are oriented in perpendicular directions in adjacent bays.

tion either, given the large investment the university had made already to renovate the stadium.

The only answer was to replace the existing roof. Owners required a design that would (1) preserve the existing architecture, (2) work within the proposed budget, (3) improve the function of the facility and increase the show-load of the roof as planned for the original renovation, (4) improve the interior stadium aesthetics, and (5) allow for an accelerated schedule so the stadium could open for basketball season in January 2003. Construction on a new roof also would have to proceed so as not to interfere with renovation work already underway. Fabric dome and space-frame dome systems were considered for the roof, but neither could meet cost, schedule, appearance or show-load requirements.

STEEL SOLUTION

South Carolina Steel Corporation and C.P. Buckner Steel Erection, Inc., of Graham, NC, teamed together to propose a unique steel solution. "We produced a preliminary design that enabled us to very quickly price both

Overhead view of the main trusses during the erection stage. The four shoring towers were used both during demolition and erection.

the materials and the erection," said David Douglass, vice president of sales for SC Steel. "Through in-house engineering and design services, we could provide Clemson with a specific solution to their problem in a matter of days as opposed to the months that most design teams would take to price a project." C.P. Buckner specializes in long-span structures and heavy lifts, and had completed a similar project, the Greensboro Coliseum, in Greensboro, NC.

Structural steel was the system of choice because it was the only solution that could accommodate the schedule and cost requirements, save the aesthetics of the facility, update the roof with catwalk systems and show-load capability, and provide fit and "connectability" within the original structure envelope. Structural steel also improved the constructability of the project by allowing prefabrication of main truss units.

The SC Steel and C.P. Buckner team met with Clemson officials to propose the removal of the existing roof system and replacement with a new roof system. "The advantages of our proposed solution was cost, aesthetics that would retain the original look, and— most of all—scheduling," Douglass said. The project was contracted as a change order to the original contract.

DESIGN CHALLENGE

SC Steel, C.P. Buckner, Geiger Engineers, and HOK / Keeshen worked together to create the final design. The roof structure is 300' by 300' with 60' square bays. Geiger suggested a concept that would use four main 300' long by 14'-deep (center-to-center of chords) trusses at the two most interior column lines in each direction, forming a "tic-tac-toe" shape at the center. It was decided that the perimeter plate girders and columns could be left intact, with new trusses framed into them. The design concept chosen for the trusses was similar to some that Geiger had designed for another arena. They are constructed using W36×210 through W36×300 top and bottom chords, with the web oriented horizontally. The web members are pairs of 8"- and 10"-square HSS members connected to the flanges of the W36s. The trusses were shop assembled (bolted) into 60' sections for delivery. The trusses double as catwalk access, providing access for maintenance and rigging purposes. The roof structure was designed to include allowances for "show load" rigging over an area of 120' by 120' at the center of the arena, a large scoreboard, and lighting.

Some of the most interesting features of the project are the connections at the intersections of the main trusses. These connections at the top and bottom chord were accomplished using 3-D plate "nodes." There were separate nodes for the top and bottom chords that were made out of 1¾" thick G50 plate. The plates were configured such that there was a pair of plates in each direction that mated with the outside face of the truss chord flanges. Each node is connected with 1¼" diameter A325-SC bolts. The truss connections to the existing perimeter plate girder were made by splitting W36×230s to form WTs that were then welded to the existing perimeter 15'-deep plate girder. This was accomplished by cutting the web of the plate girder that previously spanned across the arena back nearly flush with the edge of the plate-girder flange to form a stiffener of sorts. The WTs were placed with their stems parallel to the web of the plate girder. The flanges of the WTs formed a pair of "shear tabs" 36'' apart, and the stems were welded to the old web that had been cut back. 1½" plates mated with the outside face of the truss top-chord flanges and the flanges of the WTs, and the connection was made with 1" diameter A325-SC bolts.

Socar, Inc. of Florence, SC, designed the joists, joist girders, and connections. The typical method of using a 120'-long primary jack truss to support two 60'-long secondary joist girders at midspan could not be used. A jack truss would not produce the desired detail since it would be significantly heavier and bulkier than the supported 60' joist girders. The solution was to design two identical 120'-long, 10'-deep joist girders that "passed through" each other producing, in effect, an "X" joist girder.

Socar produced each "X" joist girder by building four 60' "halves." The four halves could then be assembled at the job site by joining the ends of the top and bottom chords together with horizontal and vertical connector plates. The connections for the intersecting chords were made using a pair of field-bolted plus-shaped plates at each chord. One "plus" was a flat plate connecting the horizontal legs of the chord angles. The other "plus" was a shop-welded assembly connecting the vertical legs of the chord angles. "These splices were a critical element," said Andrews. "We wanted to verify that we had full-penetration welds on these connector plates, so we did ultrasonic testing on the connector-plate welds."

To insure trouble-free fit-up at the job site, each of the four sets were pre-assembled at Socar's plant. Socar match-marked and drilled the holes in the connector plates for the required 96 bolts. "We could not afford any time lost with erection problems," said Socar executive vice president Cary M. Andrews, P.E. "We thought it was imperative that we do all the fit-up in shop before we loaded and shipped the sets. Because of the complexity, and the fact that we had four pieces coming together at one point, everything had to be perfectly aligned and square."

The main trusses along with the joist girders in the corners formed 60' by 60' bays, which were filled in using 60' span joists at 7'-6" on center. The joists in adjacent bays were placed 90 degrees to each other, forming a checkered board pattern, and evenly distributing the roof load to the perimeter of the building.

The roof slope presented another challenge. The slope of the roof required that the interior half of each "X" joist girder be horizontal, and that the exterior half slope down 2'-6" over its 60' length. This required each joist in the diagonal sub-bays to have a different compound sloped seat to create the necessary full contact bearing.

PROJECT FACTS

- **ROOF SIZE:** 300' by 300' = 90,000 sq. ft
- **ROOF PORTION OF STEEL SUBCONTRACT:** $4.2 million.
- **ROOF PORTION OF CONSTRUCTION COST:** $7.5 million
- **STRUCTURAL STEEL:** 740 tons (mostly in four 300'-span trusses), plus 250 tons of joists and joist girders
- **QUANTITY OF BOLTS:** 15,200 1"-diameter A325-SC "Tension Control" bolts and 3,648 1¼"-diameter A325-SC bolts
- **NUMBER OF MISALIGNED HOLES:** 20 holes, misaligned by 3/16"
- **NUMBER OF CRANES:** The two main erection cranes were Liebherr LR 1400, 440/660-ton crawler cranes with super-lift attachments. The bearing pressures under the tracks of the cranes were large enough to require two 8"-wide by 300'-long roads to be built with a bearing capacity of 3000 psf.

ROOF REMOVAL AND ERECTION

SC Steel and C.P. Buckner coordinated the removal the existing roof and the erection of a new one. LS Green of Johnson City, Tennessee was the demolition contractor who was charged with preparing the existing concrete/Tectum roof for removal, and then cartage of the roof debris off site. He prepared the roof for removal by cutting a band around each 60'-square bay and flipping this debris back on top of the remaining bay.

The roof was removed by lifting the entire 60' bay (approx. 90,000 lb) at once, including existing joists, roof slab, and roofing. Four shoring towers were installed at the corners of the center 60' bay, and the existing exterior plate girder was temporarily braced back to the seating bowl. The girders were then removed in 60' and 120' sections. Lifts were made at a radius up to 260'.

"Sequence and stability were the issues," said Paul Gossen, principal project manager/engineer for Geiger Engineers. "Everything had to be done in sequence. If the girders were not stable, even the shoring wouldn't be sufficient to brace them. But we took them out in chunks in a way that the structure remained stable."

The new structure was put into place similar to the removal of the old. Using four shoring towers, the four center 60' truss sections were set on the towers to form a box.

Next, the 120'-span trusses were set between the exterior and the box. The corners were then filled in with the intersecting joist girders. The joist bays were then set as 60' panels and the structure was decked with 3" Type "N" Non-Cellular Acoustical Deck.

The two main erection cranes were Liebherr LR 1400, 440/660-ton crawler cranes with super-lift attachments. "They allowed extremely heavy components to be lifted at long radius with ease and precision," said Doug Williams, of C.P. Buckner Steel Erection, Inc. "These state-of-the-art cranes insured productivity and safety on a very tough project." During dismantling and erection, the bearing pressures under the tracks of the cranes were large enough to require two 85'-wide by 300'-long roads to be built with a bearing capacity of 3000 psf.

SCHEDULE

Initially, the dismantling of the existing roof and the erection of the new one was scheduled to be completed in 16 weeks. The contractor later cut the schedule to 10 weeks in order to meet the January 4, 2003 renovation completion date.

Close cooperation between SC Steel, C.P. Buckner, and Geiger Engineering accelerated the design, detailing, and fabrication process. The first design coordination meeting was held on March 13, 2002 at SC Steel's office. The first 60' truss section rolled out of the shop on May 22 and the last 60' truss section on June 20. Socar was able to keep pace by making shipment within a short seven weeks from receipt of drawings.

CP Buckner removed the first roof panel on June 11 and the last girder on July 3. They set the first new truss on July 10 and placed the last piece of new roof deck on August 2. The entire construction portion of the project was completed in just over seven weeks—less than half the time originally scheduled.

"We took on something that was half-again as big as our base contract," said contractor David Boyd, senior project manager for Beers Skanska, Inc. "It was careful coordination and pushing, a lot of overtime and people working hard. We also experienced good weather and had a dry summer."

Communication between the team players was essential to the project's quick finish. "Had it not been for the teamwork, planning and implementation between erector and fabricator, the results would not have been so positive," said Williams. "The trust and commitment shown between these key players exhibited the manner in which all projects should be carried out." Quick decision-making was also important. "We made sure nothing fell through the cracks," said Keeshen. "We

PROJECT TIMELINE

- **AUGUST 2001:** Base contract for stadium renovations.
- **FEBRUARY 2002:** Need to replace the roof structure is evident.
- **MARCH 2002:** First design meetings.
- **APRIL:** Plan and schedule is debated. Eventually the roof replacement is negotiated as a change-order agreement.
- **MAY 1:** Socar receives preliminary drawings for joist-framing system.
- **MAY 22:** First 60' truss rolls out of the shop.
- **JUNE 11:** First roof panel of existing roof is removed.
- **JUNE 20:** Final 60' truss rolls out of the shop.
- **JULY 3:** Final girder of existing roof is removed.
- **JULY 10:** First new truss set.
- **AUGUST 2:** Final piece of roof deck placed.
- **AUGUST 13:** Roofing begins, two weeks ahead of schedule.
- **AUGUST 26:** Original target date to begin roofing.
- **SEPTEMBER 7:** Roofing dried.
- **JANUARY 4, 2003:** Target date of completion of entire renovation, to begin Clemson basketball season on January 5.

moved more people on site, the owner committed more resources, everyone would pitch in—so a decision that normally might have taken weeks took a couple of hours."

Gossen says it was the first time that Geiger Engineers worked so quickly with a project team. "We all knew each other from previous jobs—so it was a proven team," said Gossen. "We pushed the paperwork to the side and left the bureaucracy behind because otherwise it wouldn't have happened. Amazingly, the job was finished three weeks ahead of schedule, and the whole thing was done within the unheard-of time period of three months."

A WINNING TEAM

The project also stayed within the proposed budget. "We had an initial price, and that's what we built," said Douglass. "We were confident that we could make it happen. We delivered much more than we said we would deliver—in a shorter amount of time."

The new roof is a success aesthetically as well. "There's a brighter, more open feel with the new structure," said Boyd. "It matches the caliber of facilities at other major colleges at half the price."

Boyd says some of the project team members will attend the first basketball game in the stadium on January 5, 2003—Clemson University vs. Duke University. "It's going to be an exciting conference game," he said. "And the roof stands as a testament to being faced with a challenge to complete. Everyone worked together every step of the way, and the end result is a win for everyone." ★

David C. Douglass is vice president of marketing for South Carolina Steel Corporation, and an alumnus of Clemson University (Class of '88). Cary M. Andrews, P.E. is executive vice president of Socar, Inc., and an alumnus (Class of '76) of Clemson University. Beth S. Pollak is assistant editor of Modern Steel Construction.

One of the end connections of the main (new) trusses to the exterior plate girder (existing). In the foreground, adjustable pipe braces stabilize the existing perimeter plate girder.

OWNER
Clemson University

ARCHITECTS
Lead: HOK Sports, St. Louis, MO
Project: Michael Keeshen and Associates, Greenville, SC

ENGINEER OF RECORD
Geiger Engineering, Suffern, NY

DESIGN PARTNER/ DETAILER/FABRICATOR
South Carolina Steel Corporation, Greenville, SC (SEAA, AISC member)

ERECTOR
C.P. Buckner, Inc., Graham, NC (SEAA member)

CONTRACTOR
Beers Skanska, Inc., Atlanta, GA

JOISTS
Socar, Inc., Florence, SC (SEAA member, AISC member)

DECK
Southern Steel Products, Lexington, SC (AISC member)

DETAILING SOFTWARE
AutoCad