ULINE ARENA

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The Uline Arena has been a landmark in Washington, DC, since it was built in 1941 (Fig. 1). In its 50-year history as an event arena, the arena was home to the Washington Lions ice hockey team and the Basketball Association of America's Washington Capitols, as well as hosting tennis matches, circuses, rodeos, midget car races, ballet, and music concerts—including, famously, The Beatles' first appearance in the United States in 1964.

But the building's significance is not confined to its history and role in popular culture. For engineers and architects, the Uline Arena is very special, being one of only a handful of structures in the United States built using the thin shell technique. This "thin shell" engineering method, originally developed in Germany, uses the natural action of arches to enable huge unsupported spans to be built using very thin concrete.

STRUCTURE

The Uline Arena was built as a brick structure with a barrel-shell roof that spans 157 ft (48 m) with no intermediate supports (Fig. 2). The roof was formed of thin, sprayed concrete panels supported by external concrete

Fig. 1—The Uline Arena, Washington, DC.

arches that sit on concrete columns. The result was a huge cavernous space that was ideal for housing an ice rink—its original use—but easily reconfigured for other sports events and concerts.

Despite its engineering significance, however, the arena fell into disrepair in the 1980s, after which it had a brief incarnation as an illegal trash transfer station in the 1990s, followed by a decade as a decrepit parking garage. Now it has been given an entirely new life as an exciting office/retail redevelopment in what is fast becoming the hip Washington neighborhood of NoMa (North of Massachusetts Avenue). The developer has combined the old Arena, the adjacent Ice House—where entrepreneur Mike Uline first set up business—and two other commercial buildings to form a 2.5 acre (1.0 hectare) mixed-use site aimed at tech startups and lifestyle stores. The developer describes it as the district's first-ever "creative trophy development," designed to attract tenants who might shun traditional office buildings and want a distinctive, unique space.

REFURBISHMENT

The Arena has been converted from a single-story hangar of a building into one level of retail beneath three levels of office space. The developer's aim was to create interesting modern spaces while preserving and embracing as much of the existing structures as it could. This includes keeping much of the arena's unique ribbed, barrel-arched roof, but modifying it by removing some roof panels to build roof-level terraces (Fig. 3).

These terraces and other openings in the roof have been created by demolishing sections of the original thin concrete shell panels. But, since the panels and arched ribs were designed to act together structurally, removing any portion of the structure has an impact on the stability of the entire building. If the roof panels had been removed without any temporary support, the loads in the arched beams would deflect and push outwards thrust forces on the columns, which would undermine the structural stability of the Arena.

The project's design team studied the structure to understand the forces at work within the shell at all stages before, during, and after demolition; they even found the Uline Arena's original calculations, written in German, which the engineer used as a reference to better understand the building's structural integrity.

In the permanent condition, the new post-tensioned floors being installed inside the arena space are designed to prevent the columns from buckling and to resist thrust forces. But until those floors were built, a temporary solution was needed to prevent entire roof collapse.

POST-TENSIONING SOLUTION

One option would have been to build a traditional temporary support structure in steel. However, this would have required very large heavy frames or trusses, an option that would have been very expensive and made it difficult to build the new floors. One suggestion that came out of the value-engineering exercise to optimize the design was to find a way to put an equivalent counteracting force through internal ties within the structure—something that could be done using post-tensioning (PT) cables. The result was a very novel use of PT, in which cables were installed to act as thrust restraints rather than acting within

Fig. 2—Thin sprayed concrete panels form the barrel shell roof, which extends 157 ft (48 m) along the length of the arena.

Fig. 3—Sections of the arched concrete shell panels removed to create openings in the roof.

a concrete section. This was in addition to all of the new floors being designed as post-tensioned slabs, highlighting the versatility of PT.

EXECUTION

Groups of eight cables were installed at each column-beam location using mobile working platforms. Each cable was fixed onto an anchor block that was attached to one of the columns with a specially designed bracket, then slung completely in the air across the full 157 ft (48 m) span of the arena without any attachment to concrete before being fixed to an equivalent anchor block on the other side, with temporary hangers supporting the cables in the air until they were ready to be tensioned (Fig. 4).

The project team opted to use a "barrel" anchorage system, rather than the typical anchorage system that is usually seen on building jobs. The barrel anchor, which is more frequently used for repair jobs, is more compact and requires less space to install (Fig. 5 and 6).

Eight cables were installed at each beam location, and each cable was stressed from both ends to an effective force of 33 kip (147 kN). "The cables had to be tensioned in a very specific sequence," explains CCL engineering manager Srini Neel. 'Once the first beam location had been stressed, the next group of cables had to be stressed within 12 hours to prevent differential stresses building up.

"All the cables had to be installed, fixed to the anchorages and supported by their hangers before stressing could start at the first location," he adds.

As soon as all cables were in place and fully stressed, the main contractor was able to start demolishing the required sections of roof slab. Throughout the demoli-

Fig. 4—PT cables installed at column beam locations and supported by temporary hangers.

Fig. 5—Cables fixed to anchor blocks located at columns.

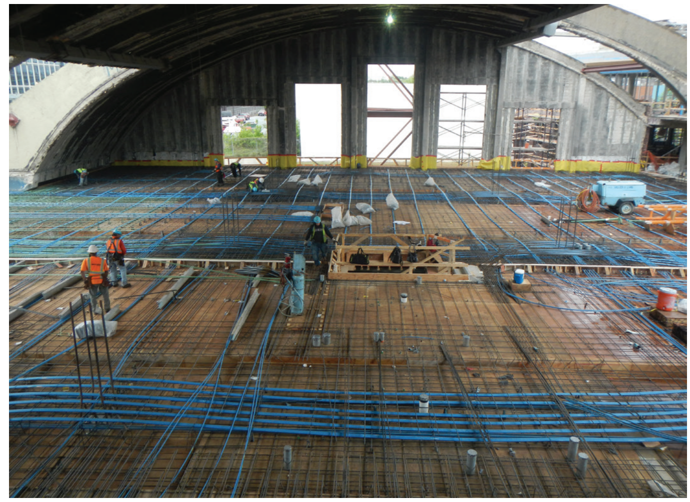

Fig. 7—Cables incorporated into the new two-way PT concrete slab acting as additional reinforcement only.

tion, the entire building was monitored using a unique deformation monitoring system that used multi-station robotic surveying instruments to collect data every 15 minutes.

The contractors' operatives had to take great care when they were demolishing the roof panels and constructing the new floor, as they were working close to exposed, highly stressed cables. The design and construction team are not aware of any other project where exposed cables have been used in isolation like this, rather than being attached to a concrete beam or slab.

The building's new upper post-tensioned floor is at the same level as the PT cables, so they were designed to be incorporated within the new concrete slab, although they do not act structurally in the permanent condition, other than as additional reinforcement (Fig. 7). The new floor is itself a two-way PT concrete slab, as are all five levels of floor in the converted arena, highlighting the important role of a variety of PT design and installation methodology in the renaissance of this historic structure.

It was an extremely successful solution that offered many advantages over traditional steel frame or truss support structures. The cables were installed very quickly, they took up very little space, and the whole system was very economical.

Location: Washington, DC
Owner: Douglas Development
Architect: Antunovich Associates
Engineer: Tadjer, Cohen, Edelson
Contractor: James G. Davis
PT Supplier: CCL USA, Inc.

Fig. 6—End block for Barrel Anchors.