The adage “time is money” is certainly relevant to many industries, but it’s particularly relevant for owners of buildings undergoing renovations, where downtime, interruptions to services, or inconveniences to customers come into play. To the casino industry, the phrase is even more literal, as interruptions to revenue-generating operations come at great expense.

When it opened in 1978, Resorts Atlantic City was the first casino on the East Coast and set the standard for casino gaming and entertainment. Situated on 11 acres (4.5 ha) overlooking the Atlantic Ocean, the 100,000 ft² (9300 m²) casino’s original structure was built in the 1920s and has undergone various renovations over the years. Recently, one of the two original towers was demolished, and a new, state-of-the-art hotel tower was constructed in its place. The final phase of this construction project was to connect the original hotel tower, lobby, check-in area, and casino with the new hotel’s lobby by creating a new promenade between them. The access would allow customers to easily reach all casino services without having to walk outside between the two towers.

**CHALLENGES**

With the new tower open, the need for the new access was immediate. Because of different floor elevations in the two towers, however, the new walkway had to slope between the two areas. This required the removal of an existing intermediate slab in the old tower (Fig. 1 and 2). Although demolition of the intermediate slab wasn’t complex, its removal resulted in columns that spanned two stories—further evaluation and remediation was therefore required.

A second challenge wasn’t discovered until construction of the walkway had begun. The new walkway was designed to be supported by a series of supports resting on the original base slab below—a slab that was thought to be a slab-on-ground. During construction, an entrance hatch was necessary for the installation of a new sloped promenade produced eight two-story columns that required strengthening. The location of the original intermediate slab is indicated by the yellow dashed lines, and the new sloped walkway slab is shown to the left.

**Fig. 1:** Removal of an intermediate slab for the installation of a new sloped promenade produced eight two-story columns that required strengthening. The location of the original intermediate slab is indicated by the yellow dashed lines, and the new sloped walkway slab is shown to the left.

**Fig. 2:** Supports for the new slab forming the promenade were located over an existing steam tunnel. This slab was originally thought to be a slab-on-ground.
was discovered in the floor of the original base slab. Because this was thought to be a slab-on-ground, the discovery of an access hatch was confusing.

Further investigation revealed that this part of the base slab was actually a suspended slab over an old steam tunnel as shown in Fig. 2. Worse yet, the existing beams supporting the slab over the tunnel had never been maintained and had severely deteriorated over time. Not only would these beams be incapable of supporting the new loads, there were serious doubts about their ability to support the current loads. Temporary shoring was immediately installed to support the slab until remediation and strengthening plans could be established.

Severely deteriorated beams, slabs, and columns in a below-grade room called the Grease Recovery Unit (GRU) were also discovered. The GRU was adjacent to the steam tunnel and functioned as a processing room for the massive amounts of grease created daily by the many hotel restaurants. Shutting it down for any length of time to perform structural repairs would cause major disruptions. Because these three areas needed to be repaired, strengthened, or both, before any portion of the new walkway could be completed, a timely evaluation, repair strategy, and installation process were essential. Recognizing the importance of proper and timely restoration, the owner required the project team to develop and implement strategies to repair the deteriorated structural concrete elements and strengthen them if needed. Accordingly, the scope of the project was redefined to include:
- Strengthening of the columns at the new walkway;
- Repair and strengthening of deteriorated beams in the steam tunnel; and
- Repair and strengthening of deteriorated beams, slabs, and columns in the GRU room.

**BIGGER IS NOT BETTER—COLUMN STRENGTHENING**

After removal of the existing intermediate slab in the old tower, a structural engineer conducted a survey of the existing conditions and determined that the columns were not made of reinforced concrete, as originally thought, but rather consisted of concrete-encased structural steel shapes. The concrete jackets on these columns had minimal reinforcement and, as a result, a structural evaluation was necessary to ensure that the steel columns that now spanned two stories were adequate to support the building loads. An analysis of the steel column showed that the doubling of the columns’ unbraced length to 20 ft (6.1 m) resulted in an under-strength condition under live load.

Traditional methods for strengthening columns involve installing a cast-in-place reinforced concrete jacket around the column to improve buckling strength. This was not a viable option, however, because it would increase the overall column size and reduce the width of the new corridor below code requirements for safe egress.

Another option was selected—the installation of very thin, high-strength, carbon fiber reinforced polymer (CFRP) sheets to strengthen the eight columns (Fig. 3). Both horizontal (hoop) sheets and continuous vertical sheets were externally bonded to each concrete column using epoxy adhesive. The resulting bidirectional composite jacket reinforced and confined the existing concrete to create a reinforced concrete member, thus providing buckling resistance for the steel column. While adding less than 1 in. (25 mm) to the column dimensions, the externally bonded composite jacket effectively upgraded the column with minimal impact on the schedule, building operations, and egress requirements.

Surface preparation to ensure bond between the CFRP and the existing concrete was very critical. After the entire surface was sandblasted, holes on the surface and deviations on the faces of the columns were patched using compatible epoxy putty filler. To prevent stress concentrations that could cause premature failure of the fiber composite, column corners were rounded to a minimum radius of 1/2 in. (13 mm). The CFRP sheets were installed using the wet-layup method by applying a layer...
of epoxy adhesive to the prepared surface, installing the sheets into the wet epoxy, and then applying a second coat of epoxy adhesive. This process was repeated for additional layers of CFRP. To ensure that the existing concrete was capable of transferring force to the CFRP, pull-off tests per ASTM D 4541 were periodically performed to check that the minimum bond strength of 200 psi (1.4 MPa) suggested in ACI 440.2R was achieved. Witness panels of the composite system were fabricated in the field and sent to an independent lab for testing to confirm the CFRP’s tensile properties.

Two columns that required strengthening were inside the Fire Control Room (FCR) where the fire alarm security systems for the entire facility were monitored. To keep the FCR in operation while maintaining all safety and code requirements, new 2-hour fire rated walls were constructed above the room and around the columns to isolate the work activities from the monitoring equipment. One column, still attached to the original façade, could not be wrapped with CFRP because access to all four faces was impossible. To strengthen this column, a new steel beam was provided at mid-height to brace the column back to an adjacent column that had already been upgraded with CFRP. Because of the very limited work area and a series of large conduits that were directly in the path of the new bracing, the new beam was fabricated in three bolt-together sections and assembled in place.

**IT’S HOT IN HERE—STEAM TUNNEL REPAIRS**

With the column strengthening under control, attention was directed to the severe concrete deterioration in the steam tunnel and the GRU room. In many of the beams, slabs, and columns, the steel reinforcement was fully exposed or completely deteriorated. These members not only required repair, they also had to be strengthened to meet current building code requirements.

In the steam tunnel, the working conditions and the upgrade design strategy presented unique challenges. Access to the beams was difficult at best. Because the access hole was only about 3 x 2 ft (0.9 x 0.6 m), the work area was considered a confined space. Key safety issues needed to be addressed, and in addition to having a dozen super-heated, high-pressure steam lines, the working area in the tunnel was very tight—giving new meaning to “back-breaking work.”

The design and construction team developed a creative approach that addressed the design requirements, limited access, tight working conditions, low headroom, air quality, and ventilation issues. To support the slab above during removal and enlargement of the beams, the entire ceiling of the steam tunnel was shored. Also, to protect both the workers and the steam lines during construction, the fully decked temporary floor shown in Fig. 4 was constructed over the steam lines—leaving the workers only 3 ft (0.9 m) of working height. Workers, equipment, and demolition debris were generally transported in and out with low-profile carts. To alleviate egress challenges, a second entrance was created at the other end of the tunnel. Also, through an engineered solution using forced air, it was possible to reduce the 90°F (32°C) temperatures inside the steam tunnel by about 15 to 20°F (8 to 11°C).

Because structural drawings of the original construction weren’t available, a comprehensive field investigation of the existing beams was needed to develop an adequate strengthening strategy. To determine the size and layout of the bottom steel reinforcement, the soffit of every beam was completely removed at quarter span to expose the reinforcement. The quarter-span location was selected because it had the least combination of bending and shear forces, thus reducing the risk of failure.

The field investigation revealed that all 10 beams supporting the tunnel ceiling slab had completely different bar configurations, giving each a different in-place capacity. This was related to poor quality control during the original construction when the actual depth and spacing of the beams was not properly controlled. For example, in some beams the bars were placed adjacent to each other with no space in between. In others, bars that should have had 2 in. (50 mm) of bottom cover were found to have as much as 6 in. (150 mm). The result of these issues was that all of the beams in the steam tunnel required both flexural and shear upgrades to carry the new loads. To strengthen the beams, an enlargement technique involving a cast-in-place reinforced concrete jacket installed around each existing beam was employed.

The challenge from a design perspective was defining the existing capacity of each beam as a reference for the
level of the required upgrade. For speed and simplicity, the design team decided to disregard the existing steel reinforcement and rely completely on the new jacket reinforcement for strength. This plan addressed the upgrades in all beams without the need to generate 10 separate designs—a common strengthening strategy. This also addressed concerns about the effectiveness of the existing steel reinforcement considering the observed level of deterioration.

To start the repair, deteriorated concrete was removed with small chipping hammers. The exposed concrete and steel were sandblasted to clean the steel and create open pores on the concrete surfaces. The roughened surface promoted strong bond with the new material and also ensured composite behavior between the old and new concrete. As shown in Fig. 5, U-shaped stirrups for shear were doweled into the slab every 5 in. (125 mm) along the beam and new bottom steel reinforcement was placed.

The supporting walls were chipped back 2 to 3 in. (50 to 75 mm) around all the beams to key the new jackets into the walls. In addition, longitudinal bars were doweled into the wall to provide additional shear transfer. The jacket was formed to provide 5 in. (125 mm) of new concrete on all three sides of the existing beams. The formwork was specially designed to allow the new concrete for all 10 beams to be pumped during a single placement. Placing concrete using the form-and-pump technique is one of the most effective methods of ensuring composite behavior of the new jacket with the existing member. Combined with adequate surface preparation, this placement method ensures that the new concrete is in full contact with the old concrete, allowing both a mechanical and chemical bond.

Because it could be pumped the long distance from the concrete truck to the repair area and would flow easily in and around the high concentration of reinforcement in the beam, self-consolidating concrete (SCC) was selected as the repair material. Acrylic windows were created in the formwork near the end of each beam to visually inspect the flow of concrete and ensure that it was pumped to capacity. At the other end of the beam, a connection port for the concrete line was installed. Because the SCC easily pumped and flowed, only a single port was required—allowing pumping through the form without segregation. With the low ceiling height, this feature was beneficial because it eliminated several connections—reducing the amount of work and workers in the tunnel during placement.

**GRU ROOM CONCRETE REPAIR AND STRENGTHENING**

The concrete ceiling at the GRU room consisted of a two-way slab and beam system that, over many years, had deteriorated to a point of structural concern. A constant combination of high temperatures and humidity in the room had caused corrosion of the reinforcement and significant concrete spalling. Further, three very large columns—each supporting more than 12 floors of the building—were deteriorated and did not meet current code requirements for lateral reinforcement. This area was so congested with equipment and piping that it was difficult to actually see the beams and slab above. There were in excess of 100 pipe hangers supporting approximately 2 tons (1.8 tonnes) of mechanical, electrical, and plumbing equipment in a 30 x 15 ft (9.1 x 4.6 m) area. Gaining clear access to the concrete for repairs would have required removing the process equipment and associated piping, causing major disruptions to all of the restaurants. Instead, the team developed an elaborate shoring plan to support the equipment and piping that allowed removal and replacement of the entire beam and slab system without any operational downtime (Fig. 6).
Once the original ceiling structure was completely demolished, formwork was placed, and a new slab and beam system was cast with new hangers and supports for the piping and equipment (Fig. 7).

To repair and strengthen the columns and meet current code minimums for reinforcement, the reinforced concrete jackets shown in Fig. 8 were designed and installed. First, 6 in. (150 mm) of concrete was removed from all four faces of the 48 in. (1200 mm) square columns. New vertical steel, doweled into the foundation, was then installed along the faces of the columns, and new closed stirrups were placed around the columns before the formwork was installed. Again, SCC was used to encase the columns, and all mixtures were proportioned to meet strict flow and curing time requirements and achieve high early strength to expedite the construction process and keep up with the very tight schedule.

**OPEN FOR BUSINESS**

Although the repaired areas were completely closed off to pedestrians, the owner wanted the casino to stay operational during the reconstruction. Safety and minimizing interruptions and noise were paramount. All demolition, drilling, and pumping operations adhered to stringent starting times for any noise-producing work. The key to success for this fast-track project was extensive preplanning by the owner, engineer, and contractors. This included developing an outline of the challenges for each work area.

On the technical side, engineering preplanning was also a key to success. Several meetings were held before and throughout construction to predict possible challenges and develop alternate repair scenarios and solutions before delays occurred. As with any successful strengthening project, the Resort upgrade project required balancing technical issues with constructibility and sequencing issues. It was also important to consider solutions and processes that addressed nontechnical issues such as access, safety, economics, and aesthetics.

The project was completed ahead of schedule as a result of a very open and cooperative relationship among the
contractors, engineers, and owner. The completion of the repairs allowed the contractor to move forward with the remaining architectural changes and open the new promenade (Fig. 9) in January 2006, ahead of schedule and on budget.

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Fig. 9: The two columns in the center of this photo of the finished walkway are the same two columns shown in Fig. 1

References


Selected for reader interest by the editors.

PROJECT TEAM

General Contractor—Perini Building Co.
Concrete Repair Contractor—Structural Group
Structural Engineer—Lochsa Engineering