A unique way to repair flat plates

Coring slabs and bonding new bars in holes corrects structural problem caused by placing top bars too low

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Figure 1. The 8½ -inch-thick concrete balconies that run around the perimeter of this residential building in Florida had cracked and sagged. The scaffolding for the repair is hung from the roof.

Innovative repair methods used on a South Florida high-rise corrected problems caused by poor construction practices. The 22-story reinforced concrete residential building was completed in 1981. The floor structure consists of a two-way flat plate which is continuous with 8-foot cantilever balconies. The 8½ -inch-thick balconies surround the building perimeter (Figure 1) and were found to be structurally deficient.

The balconies hadn't collapsed but had sagged and cracked. At first building occupants were unhappy about the unsightly cracks but weren't aware that a structural problem existed.

Two engineering firms reviewed the problem and found a major structural defect existed. The top reinforcement was placed too low in the balcony slabs. Drawings called for reinforcement to be 1 inch below the top surface of the concrete. The reinforcement was as much as 3½ inches below the top of concrete.

The distance between this top reinforcement and the bottom surface of the slab, the number of bars, and quality of material determined the capacity of the balcony to resist cantilever forces. These forces induce tension in the top of the slab and compression at the bottom. The tension is resisted by the steel and the compression by the concrete. Reducing the distance between the top steel and the bottom of the concrete slab reduced the slab's ability to resist cantilever forces.

Calculations revealed many of the slabs could barely carry their own weight. The cracking was an expected result of the improperly placed top reinforcement.

Repair alternatives compared

The strength of the balcony slabs had to be improved to support normal loads and those required by the building codes. Three repair methods were considered.

The first was to install columns at

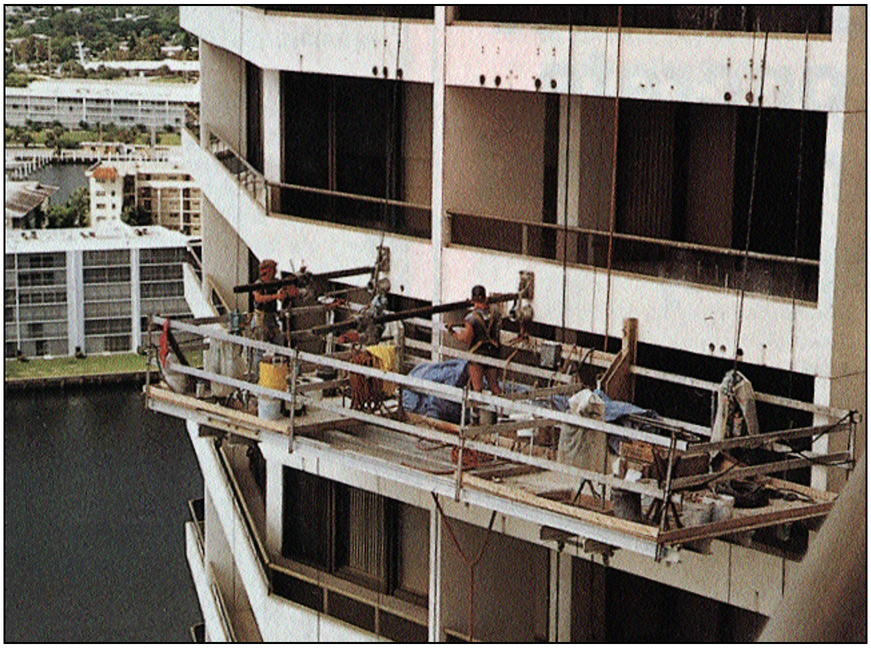

Figure 2. The working platform is big enough for two workers to drill 16- to 19-foot-deep holes into the balconies for adding reinforcement.

the edges of the balconies. The second was to install steel or reinforced concrete brackets under the balconies. The third was to add reinforcing to the existing concrete slabs.

Reducing the depth or length of the balcony was also considered but rejected because it would unbalance the floor slabs at the perimeter and radically change the look of the building. The three prime methods of repair were considered with respect to cost, disruption of the building use, and visual impact.

The use of columns would affect building appearance the most. As originally designed, the building had a strong horizontal character because of the balconies (Figure 1). Superimposing columns and brackets on photographs of the building showed that either would disrupt the clean balcony lines. The columns could have been installed with little disruption to the use of the building though. It would have been difficult, however, to lift concrete, reinforcement, forms, and other materials up the face of the building at each column location.

The second option, installing brackets, included similar logistical problems and required partial dismantling of the curtain wall. Dismantling the curtain wall would have disrupted the interior use of the building.

The third option, installing additional reinforcing steel, would restore structural integrity to the balcony slabs by adding new top bars at the correct elevation. We considered two separate methods of installing the bars.

The first method included cutting slots into the top of the concrete slab and bonding new rebar in place. This method would have involved a lot of concrete sawing and chipping but required only small amounts of new material.

But this process would disrupt building use. Also, at least 60% of the floor finishes around the building perimeter would have to be partially removed and replaced. Projected costs were high, especially where the floor finish was marble.

The second method of adding reinforcing to the balcony slabs was unique to the repair of flat plates but was chosen as the most effective repair choice. Holes ranging from about 16 to 19 feet long had to be cored into the edge of the slab. New reinforcement then had to be installed and simultaneously bonded into the holes.

This repair method disrupted use of the building the least. All the work could be performed from a scaffold outside the building.

Refining the repair method

Installing the new reinforcement below the existing top reinforcement required precise coring. The existing top reinforcement had to be located before coring the holes so that this structurally important steel would not be cut.

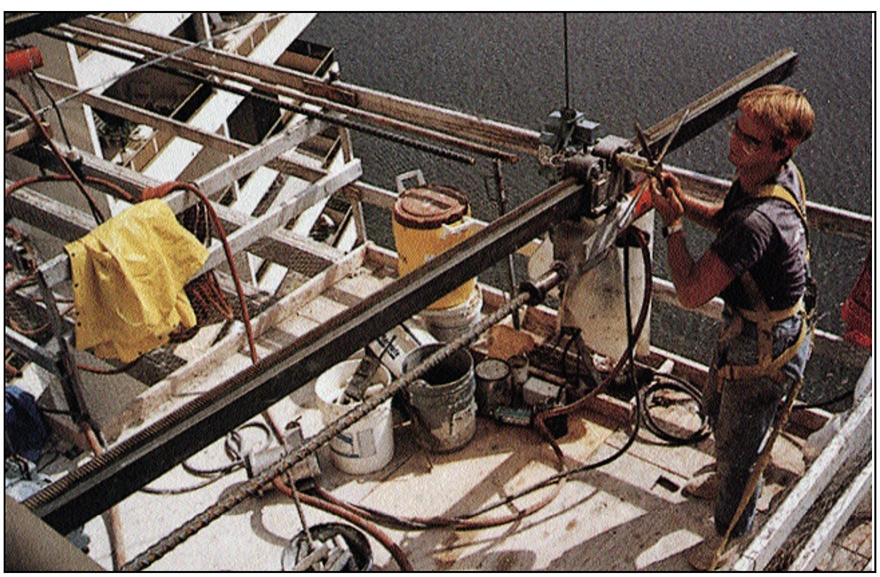

Figure 3. A worker spins the #10 rebar into a hole with a coring drill. The tapered end of the bar rips polyester resin cartridges at the end of the hole, sealing the bar into place.

One concern was the accuracy with which such a long 1⅜-inch-diameter hole could be cored. To achieve the desired result, these holes had to be cored within a vertical tolerance of ¼ inch at mid-length and ½ inch at full length.

We discussed the problem with several concrete coring contractors and a coring equipment manufacturer. We all determined that the accuracy could be achieved. The tubing used to advance the diamond bit could also guide the bit in a straight line.

We believed it would be hard to insert a 16-foot or 18-foot bar into a hole at the edge of a balcony from a swingstage. Simply sliding a #10 bar in the hole was hard enough, but depending on the method used for bonding the bar to the concrete it could be even more difficult.

Using polyester resin cartridges, slightly more than half the hole could be filled before inserting the bar. The leading end of the bar could be beveled and spun into the hole using drilling equipment. This way, half the bar extended from the balcony slab before the drill motor was attached.

If epoxy were to be used, the #10 bar could be fully installed in the hole. Then the annular space around the bar could be injected with epoxy. Using injection equipment, however, required constant cleaning. Epoxy also costs more than polyester resin. We decided to use the polyester resin cartridges.

Trial repair works out problems

Before letting the project for bid, a bidder performed a trail repair with all the bidders present. The trial repair revealed that electrical conduit embedded in the slab would be cut as part of this process. Workers also found it difficult to perform this work from a 30-inch-wide swingstage. In addition, they had to install the new reinforcement quickly so that the polyester resin did not set up before the bar was fully installed.

The problems observed during the trial repair were resolved. The conduit that would be cut was rerouted inside the building. Two of the bidders presented scaffolding methods for adequate work platforms. The polyester resin manufacturer modified its product's formula to allow longer working time.

Work completed successfully

The project was let for bid and the successful bidder was the Dana B. Kenyon Company of Jacksonville, Florida. The concrete coring contractor who coordinated the project was Drilcorp, Inc., also of Jacksonville.

Before starting the work onsite, Drilcorp cast a concrete slab in its yard, drilled more test core holes and installed reinforcement in them. These trial runs trained drillers and reduced equipment problems before the work started.

Kenyon/Drilcorp used a 10-foot-deep stage set perpendicular to the balcony (Figure 2). The stage was more than 20 feet wide, allowing two workers to drill at the same time. One driller could help the other if necessary.

In general, the stages were supported by four cables hung from support structures at the roof. These support structures consisted of counterweighted aluminum trusses and steel beams set on the roof on bearing plates. No roof anchors were necessary so no repairs were required at the end of the project.

A helicopter lifted most of the material for the support structures to and from the roof. The contractor found the helicopter more expedient than locating and setting up a crane.

Before coring holes and installing new reinforcement, the contractor had to locate the existing top reinforcement and determine existing balcony slab dimensions and slopes. A professional engineer did this and determined where the new reinforcement was to be installed.

After establishing the new bar location and slope, workers would core a hole. The coring was monitored to detect cutting of existing reinforcement or conduit. Where existing structurally significant reinforcement was encountered, the hole was abandoned and filled. An alternative location for this hole was determined and the hole recored.

An observer monitored the coring

AVOIDING THE NEED FOR REPAIR

Sometimes contractors' field forces place concrete and reinforcement with the vague sense that the structure will function regardless of the quality of workmanship. Tradespeople don't read placing drawings carefully or place rebars accurately. They seem to believe that accuracy isn't important because reinforced concrete structures are heavily overdesigned by structural engineers. We have visited projects where concrete work is done with little regard for design drawings and specifications.

These careless practices may have caused few failures in the past because early building codes were based on a conservative approach to reinforced concrete design. But in the past 30 to 40 years this has changed. Research has increased our understanding of reinforced concrete behavior. The increased understanding permits us to design less conservatively. Recent building codes and methods of analysis have allowed more cost-effective designs and economic pressures have mandated them. The structural capacity of reinforced concrete buildings designed during the last 20 years is well known and not excessive.

Because designs aren't as conservative as they have been in the past, more care must be exercised by the contractor. Unless proper care is taken in placing rebars and concrete, installing and removing shoring, and carrying out other critical tasks, more failures like the one described in this article may occur.

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operation from inside the building to check for cut conduit. When this occurred, drilling water would enter the building through the conduit. Coring had to be stopped and the conduit filled. Workers filled the conduit by ramming quick-setting polyester resin into the end of the core hole. After the resin set, they continued coring.

After coring a hole, workers inserted the polyester resin cartridges and pushed them to the back of the hole with a wooden dowel rod. Then they inserted the new rebar into the hole and attached it to the drilling motor (Figure 3). As the rebar was spun into the hole, its beveled end tore the polyester resin cartridges and mixed the material. Excess resin was collected at the end of the hole.

To complete the work, workers patched the end of the cored hole with concrete. This repair process was repeated about 2,100 times throughout the building.

Exterior painting of the building was scheduled after the balcony repairs. A thin coat of cement plaster placed over the cored holes eliminated shadow lines. After painting, it was virtually impossible to tell that a major structural repair had been made.

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