Cement Silo Repair and Upgrade

2000
Award of
Excellence Winner,
Industrial Category

Top left, initial survey and inspection of silos (4-cluster configuration)

Immediate left, completed repair strengthening and top coat process

Market conditions and the cement shortage that exists in various parts of the U.S. have made cement storage and shipping a critical issue for most cement companies. They could not afford to have any part of their delivery system out of service.

The Blue Circle Cement Company was faced with this problem. They owned six cement silos, a cluster of four and a cluster of two, built 30 years ago in the Boston area. These were constructed of reinforced concrete and stand 150 feet high and 23 feet in diameter, and were being used as load-out silos for finished product.

An initial inspection revealed cracking patterns indicative of concrete spalls as well as radial and circumferential cracking that could have been structural in nature. A structural analysis determined that the latter were indeed structural cracks caused by lack of both vertical and circumferential hoop steel. Over 30% of the required steel was missing due to design and construction oversights when the silos were originally installed. As a result, and at the recommendation of the engineer, the owner was limited to partially filling the silos (approximately ½ of their height) to avoid a structural failure. Prior to further inspection,

Grooving process

FRP rod installation

the client needed to make a key decision—repair or replace. Because of market conditions and the immediate need for storage, turnaround time was a high priority. Also, cost versus turnaround time would be critical.

Project Challenges

The repair scenario immediately introduced many challenges based on the "cluster" orientations of the silos. With a cluster (similar to four soda cans stuck together), full access around the outside perimeter was not easily achieved due to the common intersecting walls. Repair options considered included enlarging the interior walls with a reinforced concrete liner, external post-tensioning, and various interior and exterior FRP composite strengthening techniques. The interior liner posed issues related to loss of interior volume and additional weight on the foundation. External post-tensioning options were challenged by details related to passing the tendons through and around the common walls. Interior FRP options were ruled out due to the high temperature of the product in the silos.

Exterior FRP options included the commonly known sheet material. While FRP sheet material has been used on many infrastructure upgrades such as beams, slabs, and columns, this application posed a unique challenge again related to the common walls and the inability to completely confine the silo in a continuous manner. Unlike columns, which have proved to be excellent applications for additional confinement using FRP sheets, this structure did not allow any viable options to completely confine the silo. Terminating the FRP sheet at the common wall would have been the equivalent of using a discontinuous reinforcing bar for circumferential steel in a column. Demolition and replacement, although easily designed, posed issues with turnaround time, storage logistics, and cost.

Repair Solution

A new form of FRP that had only been used in lab studies or small-scale pilot projects, FRP rods, was another option. The FRP rod offered a promising conceptual option—near-surface mounted reinforcement that could restore the missing steel, offer the durability benefits of the FRP sheet option, and address the detail at the common wall in an effective, constructible, and cost-efficient manner. The near-surface mounted FRP rod is the new millennium's version of reinforcing steel slotting or "stitching dogs." With reinforcing steel, a groove is cut at the proper width and depth for bonding and corrosion protection. Reinforcing steel is then inserted and grouted in with an adhesive. The major benefits of the FRP rod versus reinforcing steel are related to the grooving process and the non-corrosive nature of FRP materials. Essentially, the groove width is minimized due to the strength of FRP rod (an average rod diameter of 3/8 inch was used), and the groove depth is minimized due to the fact that minimal protection cover over the rod is needed since it cannot corrode.

The other benefit of the FRP rod in this application is that the rods, like standard reinforcing steel, can be doweled into the common wall to a depth that will ensure complete development of the rod. By complete development of the rod, strengthening is achieved at the wall intersection.

Relationship Formed

At this point, the owner was faced with the replace versus repair decision. The fastest and most cost-effective option was the near-surface mounted FRP rod. However, the use of FRP rods

Custom swing stage access for grooving and FRP rod installation

in an application of this magnitude had never been performed commercially. The technical details to be designed, tested and applied included:

- Optimum properties of rod (strength, modulus, surface, texture, cross section, etc.);
- Optimum size of the groove to ensure proper bond;
- Optimum adhesive for bond and placeability;
- Optimum groove depths for a combination of vertical and horizontal grid;
- Installation technique for a horizontal and vertical grid pattern on a round structure;
- Optimum size and depth of holes at the common walls for doweling; and
- Lab and field verification testing for the above.

To accomplish this task, a true design-build relationship was formed among the owner, engineer, contractor, and material supplier. The benefits to the owner justified this type of relationship, considering that even minor optimizations would yield considerable savings.

Repairs Begin

Access was accomplished using customized, suspended swing stages. A comprehensive interior and exterior inspection of the silos identified and mapped out all cracks and spalls. The initial repairs consisted of epoxy injection of cracks and surface repairs using a form and cast-in-place placement technique. The repair strategy removed only one silo from service at a time for inspection, repair, and strengthening. Upon completion of each, the owner had full capacity for inventory. This procedure proved to be a major benefit.

All technical issues were solved, verified, and field-tested by the team. Installation of the rods began with the grooving operation. Customized grooving tools allowed technicians to cut the appropriate grooves in one pass. Where the groove intersected the common wall locations, a hole was drilled that was tangent to the curve of the silo to the depth determined by pull-off test results. A two-component, high-viscosity epoxy adhesive was gunned into the deeper vertical grooves.

The rods, some 150 feet long, could be handled in single pieces due to their lightweight properties. The vertical rods were then inserted into the groove and embedded in the adhesive. A second layer of adhesive was applied on top of the FRP rod. Upon completion of the vertical installation, the circumferential rods were installed. Adhesive was installed in the dowel holes in the two common wall intersections and in the horizontal grooves. Starting at the first dowel, a single length rod was inserted into the dowel hole and then placed into the horizontal groove around the circumference until it met the other common wall intersection. The remaining length was inserted into the second dowel hole. The second layer of adhesive on top of the horizontal rod was installed, and the material was then tooled to create a surface appearance that could easily be hidden with a coating for aesthetic purposes.

Fiber Optic Monitoring

Since the end goal was to have the ability to completely fill the silos, it was agreed that the silos would be fully loaded with cement while the existing reinforcement and FRP were monitored for performance. The method of measurement did not use the standard strain monitors. A new fiber optic system was installed into the FRP groove and concrete in order to measure the desired strains. Since fiber optics will not deteriorate, the system can continuously be monitored from a junction box at the base of the silo. The load test results were satisfactory to the team, and the balance of the project was started. Five additional silos were then repaired and strengthened in this manner. Ongoing quality control included pull-off tests and cores for visual inspection. The final step was to coat the entire silo with a breathable, acrylic topcoat for both durability and aesthetic purposes. The silo was coated with the owner's company colors and logos.

Project Goals Accomplished

The special features of this project and the team-oriented repair of a challenging problem made this project unique. Benefits to all parties involved were based on an open, common goal-oriented relationship among the owner, engineer, contractor, and material supplier. This unique repair using a novel material could not have been accomplished using the standard bidding process prevalent in the repair industry. Highlights of the project included:

- The repair/strengthening techniques utilized saved the owner approximately $4,000,000 and 18 months of construction time versus replacement;
- An innovative material and technique were successfully utilized on a large-scale industrial application. Over 10 miles of FRP rod were installed;
- A new fiber optic strain gauge was used to initially and continually allow monitoring of the rod and steel reinforcement;
- Part of the team included academia via university research and development support. The comprehensive and "real world" research resulted in a commercially viable technology; and
- The relationship created was very successful. It allowed a true design-build environment to produce the most viable and cost-effective solution. The process of building solutions and addressing challenges was limited only to the team's collective imagination, common sense, and technical expertise.

The most successful projects usually look as good as or better than brand new, with no inkling of the difficulty of the repair effort. This project certainly seemed to accomplish that. When a representative from the owner's corporate headquarters first viewed the series of repaired, strengthened, and coated silos, he was not impressed by the uniqueness of the team, the technology, or the repair. Instead, much to the chagrin of the repair team, his main comment was geared at how beautiful the silos looked with the company logo!

View of horizontal and vertical grooves prior to installation of FRP rod

Cement Silo

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Structural Preservation Systems
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