Polymer Concrete for Structural Restoration and Corrosion Protection of Concrete Support Columns

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Introduction

A large copper mine and refinery in the western United States had a dilemma. Their cell house, which contains over 1,500 cells, each holding more than 20,000 gallons of electrolyte, had experienced severe corrosion and structural degradation of the support columns for the tanks. These columns support the cells in their solvent extraction and electrowinning process. This process entails immersion of a stainless steel cathode or "starter plate" into the electrolyte. Pure copper is deposited onto the starter plate during this 10-day digestion process. The collected copper is then further refined at a separate location. Over time, highly acidic leakage from the cells had corroded the support columns to the point that their ability to adequately withstand the imposed load was in doubt. Additionally, the refinery desired to upgrade the facility's ability to withstand seismic activity.

The leakage, primarily copper sulfate and 25% sulfuric acid at a pH of 1.0 or less, corroded not only the concrete but more significantly the No. 8 reinforcement bar (rebar) encased in the concrete. Corrosion of the rebar resulted in an increase of internal pressure due to expansion of the corrosion products, therefore putting the concrete in high tensile stress. The direct effect of this stress was cracking and spalling of the concrete. Figure 1 shows a typical degradated column requiring restoration.

Figure 1. Column Degradation.

Discussion

The original construction of the columns used No. 8 rebar spaced 6-inches on center vertically and 18-inches on center horizontally. The refinery's standard repair procedure was to remove corrosion products from the concrete and steel and then to top them with a polymer-modified portland-cement mortar. This standard repair method requires two (2) to three (3) days per column, and although temporarily affective, did not meet the company's desire for a long-term solution. They decided upon a new approach using a polymer concrete (PC), which is a bisphenol A based-epoxy. This material is designed for maximum flowability, mechanical properties and chemical resistance. The PC repair system utilizes the polymer concrete for encapsulation, chemical protection, mechanical support and resistance to physical abuse. Figures 2 illustrates the method by which the stainless steel rebar was attached to the columns after surface-preparation. Stainless steel rebar was imbedded into the concrete floor using an epoxy mortar. Channels were saw-cut vertically in the concrete column. These channels provided a recess into which the rebar was bent and then secured into place with the epoxy mortar. Grouting of the rebar with this high strength epoxy mortar also served to provide tensile stress relief. By lowering stress relief, corrosion rates are reduced.

Figure 2. Stainless steel rebar bent and grouted into the channels.

To further ensure structural integrity and to upgrade seismic capabilities, the company chose to use fiberglass reinforcement (FRP) strips and wraps under the PC. The strips were installed vertically on the columns and a fiberglass fabric was wrapped around the columns horizontally. The columns were formed and the polymer concrete was poured into place completely encapsulating the columns, the rebar and the FRP. This method required two (2) days per column. To date, 75 columns have been repaired using this method. Figures 3 and 4 show the forming and pouring of the PC. Figure 5 shows the PC after the form has been removed and the FRP that was applied to the columns.

Figure 3. The forms placed around the column.

Figure 4. Pouring of the polymer concrete.

Figure 5. Columns after removal of forms.

As mentioned earlier, an important property of the PC is the flowability. The test for this property is ASTM C-143 and measures the “slump” of the polymer concrete. Slump is defined as the amount that the molded cone of fresh paste sags, or slumps, from the original height of a standard 0.5 cubic foot molded cone (Figure 6). A slump of 6 inches is considered to be flowable. This particular polymer concrete exhibits a slump of 8-inches, which is very flowable. Figures 7 and 8 illustrate the flowability of the polymer concrete mixture. Table 1 lists some of the other physical properties of the polymer concrete used on this repair that were important considerations.

Figures 6-8: Filling the slump cone, cone removal, measurement of polymer concrete slump.

Table I:

Property at 7-days	**Value**
Density	135 pounds / cu. ft. (2.2 gm / sq. cm)
Compressive strength	12,000 psi (844 kg / sq. cm)
Flexural strength	3,000 psi (211 kg / sq. cm)
Modulus of Elasticity	1.08 x 10^6 psi (7.6 x 10^4 kg / sq. cm)
Shrinkage	0.09%
Tensile strength	2,400 psi (169 kg / sq. cm)

The PC is roughly three times as strong as a portland cement mix (about 4,000 psi (281 kg / sq. cm.)) and is not chemically affected by the electrolyte. These properties make it an ideal product for the column restoration. As expected, none of the 75 columns repaired to date have exhibited any signs of failure and have required no maintenance since the repair program commenced in early 2007. Coatings will typically have a service life of 8 to 15 years depending upon the exposure and physical abuse. However, in this case, typical service life of coatings was six months. Their service life is also affected and somewhat limited as a result of application thickness. Coatings are generally applied at thicknesses ranging from a few mils up to a few hundred mils. Polymer concretes, however, are applied at a minimum thickness of 1 inch and may be applied as thick as 18 inches. The thickness of barrier coatings determines the overall permeability, which is a measure of water vapor's ability to pass through a material. If the coating is less than 250 mils, the method used to determine permeability is based on the water-vapor transmission (WVT) test ASTM E-96 or ASTM D-1653. Permeance is calculated from WVT. Permeability is obtained by multiplying permeance by thickness. A permeability of 10^{-8} (1.49 x 10^{-17} grams/Pa•s•m) or less is generally considered to provide a good barrier coating. With PCs, hydraulic conductivity, measured per ASTM D-5084, is a more useful test. Hydraulic conductivity measures the volume of water that permeates or flows through the barrier coating. The Environmental Protection Agency (EPA) requires a value 10^{-3} m•s^{-1} or less for secondary containment structures. The PC utilized on this restoration has a hydraulic conductivity of less than 10^{-15} m•s^{-1}, which is about the practical lower limit for the test method. Also due to the thickness, and other considerations, the service life of a polymer concrete is longer and requires far less maintenance. Experience with PCs by this manufacturer has shown no failures after 15 years of service. Laboratory evaluations coupled with field observations indicate the service life of PCs to be typically greater than 25 years. Figure 9 illustrates the completed column, including a protective topcoat for the FRP reinforced concrete. Although not needed for functionality, the topcoat was extended over the PC for aesthetics and coating integrity.

Figure 9. Completed column repair.

Many users of polymer concretes will entirely replace portland concrete with a full thickness of the polymer concrete. This is particularly true when extended downtimes are prohibitive. The lengthy cure time for standard portland based cement prior to receiving a protective coating is unacceptable for many facilities. After placement, polymer concretes may be placed into full chemical service after a 24-hour cure. Furthermore, with the strengths achieved with PC, it is usually possible to reduce the overall thickness to about ½ of that commonly used with portland concretes. Typical thicknesses for PCs range from 1-inch to 4-inches. Polymer concretes may be engineered, formed and placed in the same manner that one would employ with a portland concrete structure. They also are reinforced in the same manner as portland concretes. Polymer concrete thicknesses are typically much less than that of the portland concrete, therefore smaller diameter rebar is often used. At a thickness of 1 inch, one would use No. 2 or No. 3 rebar instead of a No. 6 rebar commonly found with portland concrete constructions.

The specification for this project was developed by the manufacturer's field engineer and the facility's maintenance engineer. The specification development considered cost, ease of installation, downtime, engineering parameters and corrosion control. It also called for a seismic evaluation, which was conducted by the manufacturer of the FRP system. Due to the ease of installation, the facility's local preferred contractor was able to perform the work.

Conclusion

Polymer concretes, which do not contain portland cement, have demonstrated tenacity as a protective barrier material in this difficult application and many others. This application required corrosion protection from a severely aggressive electrolyte, as well as protection from physical abuse. Other essential requirements were a system affording both ease of use and a quick turnaround time. Polymer concretes are also proving to be cost effective alternatives to using portland cement-based concretes with chemical-resistant topcoats for corrosion protection. The cost of maintenance for polymer concretes per year of service life is significantly less than that of concrete with applied barrier coatings, which may require multiple re-applications over the same number of years of service.

References

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2. ASTM Annual Book of Standards, E-96, Test Method for Water Vapor Transmission of Materials, Volume 04.06.
3. ASTM Annual Book of Standards, D-1653, Test Method for Water Vapor Transmission of Organic Coating Films, Volume 06.01.
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