Award of Excellence 2012

Industrial Category

Rehabilitation of Kellogg Grain Storage Silos

Querétaro City, Qro., Mexico

Submitted by BASF

A well-known food company owns grain storage silos located in Querétaro City in the central region of Mexico. This project consisted of the rehabilitation of two batteries similar in dimensional parameters but different in the number of silos, date of construction, and in some of the abnormalities identified. Both units are connected only in terms of communication by a mechanical room in the top and an underground mechanical corridor in the bottom. The reinforced concrete silos were built using slip-form construction.

The first battery consists of four main silos and three inter-silos attached to a service tower that houses mechanical equipment required for the silos' operation. This structure was designed in 1968 and built around 1970; the height of the units is 115 ft (35 m).

The second battery consists of eight main silos and five inter-silos, also attached to a service tower. This unit was designed in 1978 and built in 1980. The dimensions of the silos and height of the structure are the same as those of the older battery.

The owner of the structures, Kellogg de Mexico, required a comprehensive evaluation of the silos as part of its continuous effort to fulfill and exceed the highest international standards in terms of the health and safety of both its products and facilities. A number of in-depth studies were performed and results from those studies enabled the team of designers and specialty contractors to specify a variety of remediation measures aimed at providing the structure with greater structural integrity and extended durability.

Exterior view of silo facility

THE PROBLEMS

The newer batteries of the silos had a significant number of construction joints that were in such poor condition that some of the silos had been deemed unusable and were not in operation, despite the client's storage needs. The construction joints were found to be highly porous with delamination and extensive cracking present. Due to the number and proximity of some construction joints, the grain stored in several of those silos had eroded the interior surface of the concrete walls to such an extent that the cementitious matrix had almost disappeared, leaving the coarse aggregates barely fixed in a reduced wall section. In addition, large cracks were present throughout the interior walls.

The older battery had considerably fewer construction joints than the new one; however, in some of those silos, there were numerous clearly defined vertical cracks in the interior—regularly spaced and widely opened. The remaining silos in use were in relatively good condition because of constant intensive maintenance, and they met the safety and quality requirements of the client.

A number of abnormalities were common to the concrete in all structures and included:

- Minimal concrete cover over reinforcing steel where reinforcing steel scanning of the silo walls revealed that most of the existing steel reinforcement was located in the outer quarter of the wall sections;
- Carbonation depth that had reached less than 5% of the total wall reinforcement. However, further analytical studies indicated that more than 10% could be affected in the next 5 years from the time of the study if no protective measures were implemented;

- Carbonation depth that was measured deeper near construction joints where most of the corroded steel was found; and
- Chloride content in the concrete that was, in general, below the limit associated with steel reinforcement vulnerability to corrosion, except in the highly porous construction joints.

Detailed geotechnical and structural models were developed using finite element and dynamic three-dimensional (3-D) computer modeling software, and a number of recommendations were made based on the analysis of the models. While the existing steel reinforcement was adequate to resist the direct tension forces associated with the loading and unloading operations for a single silo, there were other phenomena that induced high tension stresses in the inner face of the walls. The biggest force occurred from bending stresses that were due to the restriction of a single unit to freely deform and the temperature gradient present from solar heating on the outside of the silos. To provide compressive stresses in the concrete walls, thus avoiding further vertical cracking, an active post-tensioning system was used. Regarding the foundation, because of the eccentricity that some of the loading and unloading operations induced and the overturning moment associated with earthquake forces, restrictions were imposed on both those operations and the maximum stored weight.

THE SOLUTIONS

Structural integrity of the silos was restored by a number of remediation measures that included epoxy resin injection of cracks and concrete patching of construction joints. Concrete patching without risking the formation of cathodic areas was possible because of the relatively low and localized chloride content. Structural section restoration and strengthening of the walls in the silos with an improved resistance to abrasion was achieved by the installation of an FDA-approved epoxy lining reinforced with glass cloth.

Because of the continuity of the silo walls within a given battery, an extremely detailed design of the post-tensioning system was developed. The system involved drilling through both ends of common walls and opening small boxes in the interior of the silos to allow for the placement of tendons. Drilling to that length was not possible without potentially damaging both the existing steel reinforcement and concrete. This also provided a means to control the levelness of the cables. Change of direction in the cables was carefully designed so as to achieve a smooth change in the local direction of the stresses within the concrete.

Another problem encountered involved horizontal cracking that was due to creep in the concrete from a long-sustained compressive live load.

Existing condition of silo wall prior to rehabilitation

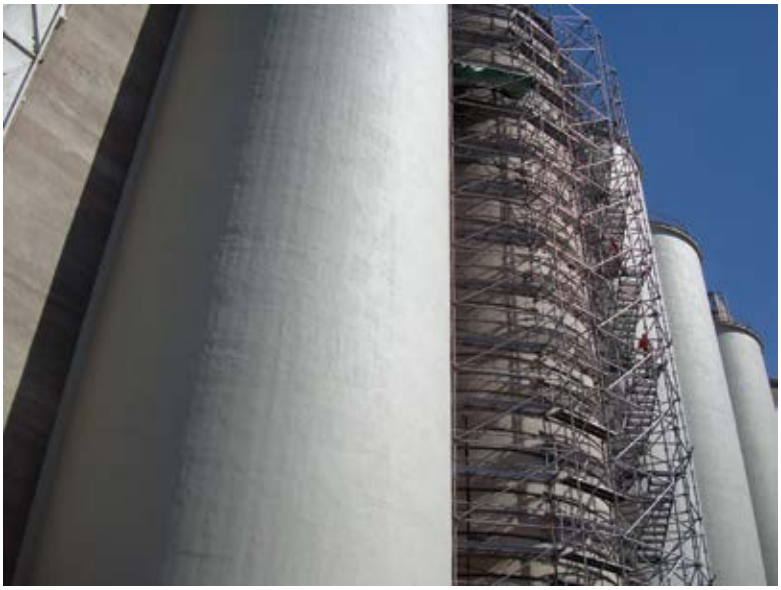
Epoxy injection of cracks

Worker applying reinforcing mesh to silo wall

Evidence of the subsequent quick unloading from the post-tensioning was present in the hoppers' columns in the basement. These were strengthened with externally bonded carbon fiber-reinforced polymer (CFRP) wrap. In addition, CFRP strengthening was used in the hopper beams to provide increased resistance to shear and torsion.

To protect the concrete in the system of silos from additional carbonation, a carbon dioxide diffusion barrier system was applied on the exterior. The system used was a both a modified polymer and an elastomeric acrylic coating.

Post-tensioning cable installation



View of finished exterior covering post-tensioning cables

Finally, taking into account the variety of solutions and their potential interactions, an extensive testing program during the rehabilitation work was implemented. This allowed for adjustment of the remediation measures on a case-by-case basis and involved everything from the viscosity of the epoxy injection to the post-tensioning force that was applied. All activities were designed and scheduled to comply with the food safety standards of Kellogg's.

SUCCESSFUL COMPLETION

The use of both state-of-the-art materials and technologies to restore and structurally strengthen the walls of the silos allowed the owner to confidently use and operate a number of units that had been unused because of their defects. The finished surface allows for natural self-cleaning of the walls, avoiding localized areas that contain old and contaminated product with considerably lower maintenance costs.

The active post-tensioning system with a controlled program of loading and unloading operations provided the silos with a higher level of structural reliability. Other protective measures, such as the exterior coating system, will improve the durability of the storage units and provide an extended service life. It should be noted that the rehabilitation work was performed while a minimum number of the silos were in operation, which gave the project an even greater level of complexity.

All of the remediation measures were designed and scheduled to comply with the client's food safety standards. The quality of their products was met with the reduced number of silos they were previously using and the same had to be accomplished both during and after the work was performed. The successful completion of the rehabilitation project helped the owner to achieve the high standards set for its facilities.

Kellogg Grain Storage Silos

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