Prescription for Repair

The Triage, Life Support and Subsequent Euthanasia of an Existing Precast Parking Garage – Part 3

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As a part of Pennoni's on-call contract with an existing client, the Philadelphia structural division investigated and developed repair bid documents for an existing, three-level, 1,200-space precast concrete parking garage during the last quarter of 2012. Part 1 of this series (September 2013) described the existing structure and summarized Pennoni's observations and material testing results. Part 2 (November 2013) presented an analysis of those findings. This article conveys Pennoni's conclusions regarding the feasibility of repairing the garage in order to extend its service life.

The third level precast, prestressed inverted "T" concrete girders that supported the 16-inch deep double tees were in extremely poor condition. The corresponding second level girders were also in poor condition due to high chloride content, and several locations exhibited large subsurface delaminations. The cast-in-place, post-tensioned concrete inverted "T" girders that supported the conventional 24-inch-deep precast double tees were generally in fair condition due to limited deterioration at isolated areas. In addition, the extremely high chloride content of all of the concrete, in conjunction with ongoing carbonization, was expected to cause deterioration to accelerate in the near future.

Material testing indicated that the existing concrete in the garage girders had a chloride content that was significantly greater (25 times) than the limit recommended by ACI for prestressed structures in a moist environment that are exposed to chlorides in the form of either admixtures or deicing salts (0.06%). None of the previous testing performed in 2002 or 2005 included chloride testing from the beams, therefore the previous reports failed to reveal the true nature of the current rapid demise of the garage. Extrapolating the results of carbonization analysis indicated that the depth of carbonization would reach the embedded reinforcing in approximately two to three years. Significant repairs would be required within that time to prevent permanent damage to the embedded reinforcing.

Service Life Analysis

Pennoni determined that the practical remaining operational service life of the existing parking structure was approximately two years. This was commensurate with the large spalls and severely corroded reinforcing, observed during the site visit, at the girders associated with the barricaded portion of the third level. In addition, the service life calculations were considered representative of the remaining portions of the garage, which indicated that some if not all of the other third floor girders would also begin to corrode in the same fashion within the next two years, and the second level would follow shortly thereafter.

From an engineering perspective, the service life of a structure is considered to be over when the extent of deterioration renders the facility inoperable due to impending hazards to public safety, and remediation is required in the form of complete repair or replacement. Therefore, the end of a structure's service life does not mean that it is in a state of imminent collapse, but instead implies that the structure can no longer safely function or support minimum loads as required by the building code.

In the case of this particular garage, vehicles and pedestrians would no longer be able to use the entire garage for parking, similar to the current partial loss of service at the third level. Pennoni estimated that, within the next two years, the garage would have to be progressively closed as additional areas became unsafe, until eventually the entire facility would be completely out of operation. The eventual and unavoidable loss of use of the entire garage by the current occupants would therefore have a direct impact on the practical everyday operations of the facility in the very near future.

Typically, a garage constructed with precast concrete components should have a useful lifespan of 40 to 50 years before significant repairs would be required. In this case, the actual service life of the garage in the absence of any remediation will be approximately one-half of this duration. The shortened lifespan of the garage is directly attributable to the use of chloride-containing admixtures in the main girders.

Feasibility of Repairs

It is clear from the results of the condition assessment, material testing and investigation that the primary source of the internal reinforcing and concrete deterioration in the garage was the presence of excessive chlorides in the concrete in conjunction with continued exposure to deicing salts. In addition, it was anticipated that further carbonization of the concrete would cause additional deterioration of the structure. Therefore, any solutions involving the repair and restoration of the garage to extend its service life would have to address the presence of the high chloride content.

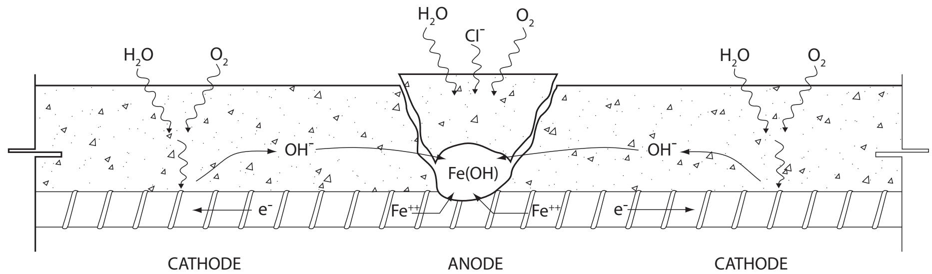
Typically, a chloride extraction process, such as Norcure by Vector Corrosion Technologies, or an active galvanic protection system, such as Ebonex or Vectrode TiTape by Vector Corrosion Technologies, could be used to reduce or remove the chloride ion content or arrest the current rate of deterioration in conjunction with conventional concrete repairs. However, the presence of the high-strength prestressing steel precluded the use of chloride extraction processes or active galvanic protection systems due to the potential for hydrogen embrittlement of the strands, as described by *State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed Concrete Structures*, published by NACE International – The Corrosion

Society. Damage to the internal prestressing steel due to hydrogen embrittlement would clearly further increase the degradation of the structure.

Pennoni performed additional research as part of an exhaustive effort to verify that there were no other practical long-term repair methods of lowering the extremely high chloride content besides the types of systems mentioned above. This led to a state-of-the-art technology, known as nanoparticle treatment, which is intended to address the corrosion of internal reinforcing of distressed prestressed concrete beams. *ACI Materials Journal* Technical Paper 109-M60, "Corrosion Mitigation in Reinforced Concrete Beams via Nanoparticle Treatment" (Kunal et al.), contains a thorough discussion of this process, which is not commercially available at this time.

Based on the results of the referenced ACI study, the potentials during and after the nanoparticle treatment were as negative as -1200 millivolts (mV). However, the threshold for hydrogen embrittlement in high-strength prestressing reinforcement is around -1060 mV (or more positive if the concrete pH is lower than 13). Therefore, even this new technology is not applicable for the repair of the garage. As a result, Pennoni was confident that no viable options existed for effectively reducing the chloride content in the existing girders to an acceptable level that would allow for a conventional repair. In addition, the presence of high-strength bonded reinforcing tendons would make conventional repairs very difficult and time-consuming because of the need to de-tension and then re-tension any strands impacted by deterioration as a part of the overall remediation process.

Furthermore, conventional concrete repairs, in the absence of chloride extraction or an active or passive galvanic protection system, would result in the accelerated deterioration of the remaining existing concrete due to the interruption of the incipient anode effect (see *Figure*). The incipient anode effect is a phenomenon by which steel corroding under the influence of chloride contamination dissolves, causing the formation of iron "ions" (tiny charged particles of iron). Simultaneously, electrons are released that flow along the bar and react with both air and oxygen at some point remote from the corrosion location. The corroding areas are therefore supplying electrons to surrounding areas of steel, effectively providing localized cathodic protection to the adjacent steel. If the corroding area is removed and a repair patch is installed, without dealing with chloride contamination in adjacent areas, the natural cathodic protection system is disabled. As a result, new corrosion cells rapidly occur on either side of the repair, resulting in accelerated premature failure of the surrounding concrete.



Part 4 will appear in a future issue and discuss recommendations for the temporary stabilization and ultimate replacement of the garage.■