REPAIR AND LONG-TERM PROTECTION OF WASTEWATER INFRASTRUCTURE: GOLD BAR INFLUENT CHANNEL NO. 2

BY DARYL PREFONTAINE

The harsh environmental conditions inside wastewater treatment plants (WWTP) can cause significant deterioration and damage to the reinforced concrete structures that are necessary for the long-term operation of these facilities. In most municipalities and jurisdictions, the reality is that the existing sewer pipe network flows to only one location and there are no alternate sewage transport or treatment infrastructures available as a secondary backup in the event of the collapse or failure of a critical structural component.

As a result, plant managers and personnel responsible for the maintenance and operation of these facilities recognize that long-term, reliable methods for the repair and protection of the concrete structures are an important investment to ensure that their plants continue to meet current treatment capacities and to accommodate expanding future needs.

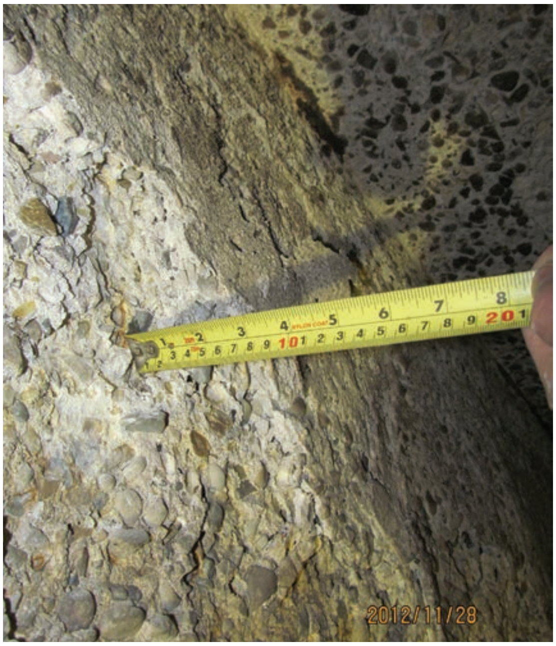

Fig. 1: Extensive depth of concrete deterioration on channel walls

It is generally necessary that a WWTP remain in operation during maintenance or repairs. The challenge of temporarily isolating and diverting influent flow can therefore add to the difficulty and cost of an already complex repair scenario. Further, ensuring the safety of the personnel accessing the hazardous environment inside the enclosed channels and tanks adds further complexity. Due to the challenges involved, it is imperative that long-term solutions for the repair and protection of these critical infrastructures are developed. Providing a resilient, long-term structural protection assembly can be significantly more cost-effective over the long life cycle of a plant, in comparison to lower initial-cost measures that will require more frequent repairs or re-application in the future.

CONDITIONS THAT PROMPTED THE REPAIR PROGRAM AT GOLD BAR WWTP

Three influent channels are located at the Gold Bar WWTP, including the original influent channel (constructed in 1955), and Channel Nos. 2 and 3, subsequently constructed in approximately 1979 to meet the plant's increasing demand requirements. Influent Channel No. 2 consists of a reinforced concrete rectangular tunnel in excess of 295 ft (90 m) long, with interior width varying from approximately 7 to 10 ft (2.13 to 3.05 m), and interior height varying from approximately 6.5 to 10.75 ft (1.98 to 3.28 m). The channel structure is entirely below grade, with 12 in (305 mm) side walls, a 15 in (381 mm) floor slab foundation, and a roof slab varying from 12 to 15 in (305 to 381 mm) in thickness. Portions of the roof structure include 12 in (305 mm) wide reinforced concrete beams where the channel roof structure also forms the main floor of a process building. A partial height weir wall in a portion of the channel provides emergency overflow capacity into an adjacent diversion channel. Several expansion joints were provided along the length of the buried channel structure, and a fiberglass-lined venture flume is located in one zone to aid in the measurement of wastewater flow rates. The channel construction includes an isolation gate and roof access hatches in localized areas.

Influent channels transport raw wastewater from the plant outskirts to the grit tanks, screen chambers, and initial pre-treatment areas; and thus are often exposed to the harshest and most corrosive environments within a WWTP's concrete infrastructure. Raw influent and partially treated wastewater typically contain relatively high concentrations of hydrogen sulfide (H_2S) gas, which forms sulfuric acid when in the presence of moisture, oxygen and bacteria. The sulfuric acid then attacks the concrete, exposing the concrete matrix and underlying aggregate, and eventually the embedded reinforcing steel. Typically, the concrete deterioration due to H_2S environmental exposure has been observed to be most severe within the enclosed portions of WWTP structures—such as inside buried channels, and covered grit and clarifier tanks. This deterioration is generally concentrated in the zone between the water level and the underside of the roof enclosure above. The rates of concrete deterioration and microbial corrosion vary depending on the concentrations of sulfides in the wastewater, flow rate and level of turbulence, and the subsequent rate of H_2S release. Hydraulic conditions that result in splashing, misting, or flow constrictions often result in an increased amount of H_2S gas being released from the wastewater.

Fig. 2: Existing column deterioration

During an interior inspection of Influent Channel No. 2 in 2014, after approximately 35 years of service and H_2S exposure, between 1.25 to 3 in (32 to 76 mm) of deteriorated and unsound concrete was identified on many interior surfaces during hammer-sounding of the channel walls, columns and roof members (Fig. 1 and 2). The extent of deterioration varied from the roof to the low water level, up to the full interior height of the channel walls in some locations. Significant erosion and loss of concrete wall thickness had occurred in many locations, often to the depth of the reinforcing steel (Fig. 3). Similarly, the concrete cover on the underside of the roof slabs had deteriorated to expose the lower mat of reinforcing steel in many locations. Beam stirrups and bottom layer reinforcement steel were also exposed and heavily corroded, with visible loss of cross-sectional area.

Fig. 3: Exposed reinforcing steel at beam and wall surfaces

The Influent Channel's original construction details provided approximately 1.5 to 2 in (38 to 51 mm) of concrete cover over the embedded steel reinforcing steel. Therefore, the severe extent of concrete cover loss, the resulting reduction in concrete member thickness, and loss of reinforcing steel cross-sectional area were considered to be of structural concern in the affected areas, causing a significant reduction in load-carrying capacity.

In addition to the structural concrete deterioration, the inspection revealed that expansion joint seals were missing or damaged and thus no longer effective, and that metal gratings and handrails were severely corroded above the wastewater flow level (Fig. 4).

Fig. 4: Severe corrosion of metal railings above wastewater flow

REPAIR OBJECTIVES

Planning and design of a repair and protection program was undertaken upon completion of the structural condition assessment with the following objectives and criteria identified by the project team:

- Repair and restore deteriorated and damaged portions of the concrete influent channel structure, to achieve the load-carrying capacities required in the original design;

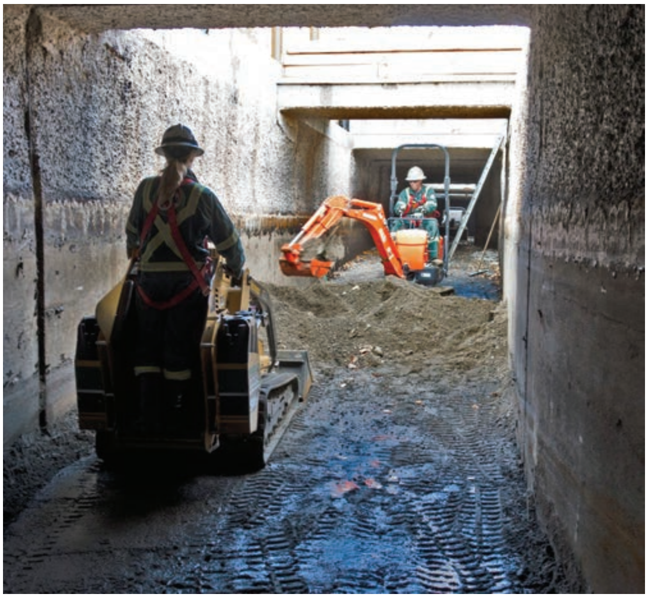

Fig. 5: Initial removal of channel debris

Fig. 6: Wall reinforcing and bracing

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Fig. 7: Reinforcing and base of HDPE liner at curved wall

- Provide increased load-carrying capacity in localized areas where necessary to meet current loading and usage requirements at the facility;
- Incorporate enhancements, where cost-effective, to improve the overall structural durability and to minimize the vulnerability of smaller-dimension structural members, such as beams and columns, to sulfuric acid attack and cross-sectional loss;
- Incorporate a protective coating or liner assembly to provide long-term protection for the concrete channel structure against the harsh environmental H_2S exposure and resulting sulfuric acid attack. As a project criteria, the plant maintenance team identified that the protective measures must minimize the need for future re-coating, re-application or repair requirements;
- Improve the degree of leakage resistance and protection of the expansion joint assemblies to H_2S attack, impact from submerged debris, and cleaning operations; and
- In general, maximize the remaining service life of the concrete infrastructure.

REHABILITATION STRATEGIES

Based upon the identified project criteria and objectives, a structural repair and protection program was developed and undertaken in 2015 that included the following measures:

- Removal of channel debris (Fig. 5), removal of deteriorated and unsound concrete, and substrate surface cleaning and preparation to a CSP 5 concrete surface profile, in accordance with ICRI Guideline 310.2R[1], prior to the placement of new reinforcement and concrete overlay materials;
- Installation of a cast-in-place, bonded, reinforced concrete overlay to the affected portions of the channel's interior roof and wall surfaces. A minimum overlay thickness of 4.5 in (114 mm) was provided at the underside of roof slabs, and to designated portions of sidewall surfaces, to no less than 16 in (406 mm) below the lowest water level. In much of the channel length, the entire wall height was covered with the new overlay assembly to improve constructability and detailing (Fig. 6 and 7);
- The overlay thickness was designed to provide the 2 in (51 mm) concrete cover required by ACI 350[2], plus provide sufficient depth for installation of hooked steel dowels and reinforcing bars;
- A highly durable, sulfate resistant, self-consolidating concrete mix was specified to provide the low shrinkage, low permeability, pumpable concrete necessary for the overlay construction and subsequent environmental exposure;
- The relatively thin roof beams were eliminated, and additional reinforcement incorporated into the overlay thickness at those locations. The elimination of the beams reduced the trapped pockets of H_2S gases occurring at the underside of the roof slab between the underhanging beams, and eliminated the inherent vulnerability of the small beam members to sulfuric acid attack;

- A proprietary high density polyethylene (HDPE) protective liner assembly was cast into the surface of the new concrete overlays. Although originally intended for new construction, the protective liner material was identified as having suitable rehabilitation capabilities, and a service life significantly in excess of that provided by typical surface applied-coating materials for the H_2S exposure and the acid and microbial attack typical inside WWTP influent channels. The protective liner consists of a 1/8 in (3 mm) thickness of HDPE with integral rows of 1/2 in (13 mm) anchor studs that provide mechanical interlock and bond to the concrete substrate (Fig. 8). The smooth exterior surface of the liner provides improved flow rates for the wastewater influent, compensating for the reduction in hydraulic flow capacity due to the thickness of the new concrete overlay;
- Expansion joints were replaced with a multi-layer assembly consisting of a compressible closed-cell foam backer adhered within the joint gap, a flexible sealant, and a watertight polyolefin gland adhered to the substrate. To protect the expansion joint assembly against damage, a neoprene gasket and proprietary rubber-encapsulated metal cover plate assembly was provided at areas that were vulnerable to impact from stones and debris; and
- In accordance with plant requirements, only materials and components that met the requirements of ACI 350 and NSF/ANSI Standard 61[3], suitable for potable water contact and submerged exposure, were used in the construction of the structural repair and protective measures for the project.

DESIGN AND CONSTRUCTION CHALLENGES

The structural design of the new concrete overlays was intended to provide fully composite behavior between the undamaged portions of the existing structure and the new concrete overlay, through material bonding and sufficient reinforcement dowelling at the shear interface (Fig. 9 and 10). The recently-developed ACI 562-13[4] Repair Code Requirements provided valuable guidance for the design, bond interaction, and required transfer of forces between the existing concrete channel and the repair overlay assembly. Other considerations and requirements for design of the concrete overlays in this application were identified in ACI 350, including concrete cover, reinforcement ratio and spacing requirements.

Integration of the new HDPE protective liner into the outer surface of the concrete overlay provided some design challenges. Although manufacturer's recommendations and guidelines were available for typical splices, corners and transitions, it was necessary to develop details for many of the project-specific requirements. Details for HDPE liner transitions into the existing fiberglass venture flumes, the new stainless steel expansion joint nosings, the piping and process equipment penetrations, and other non-typical locations were developed and refined in a collaborative basis between the engineers and contractor, throughout the design and construction phases of the project.

The construction of the bonded overlay and HDPE protective liner assembly also provided some challenges for the contractor (Fig. 11 and 12). It was necessary to ensure that formwork and


Fig. 8: Preparation of HDPE liner for installation


Fig. 9: Formwork, bracing and drilling of reinforcing dowels

Fig. 10: Overlay reinforcement at overflow wier

Fig. 11: Wall liner, reinforcement, and formwork

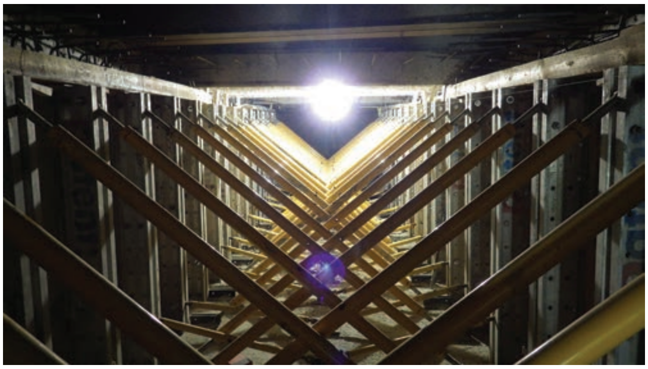

Fig. 12: Formwork and bracing

Fig. 13: Trial fit of HDPE liner prior to erection of formwork

bracing systems introduced the fewest possible number of penetrations through the protective liner, to minimize liner patching requirements before returning the channel back into service. Additionally, the lack of formwork tiebacks into the concrete substrate also introduced the challenge of ensuring that the layer of HDPE liner did not wrinkle or warp during placement of the self-consolidating concrete overlay materials (Fig. 13).

The HDPE liner is produced in long rolls, which requires that all edges be field-welded to provide the final water-tight assembly after removal of the construction formwork materials. Field welding was performed using an extruded welding rod of the same HDPE material along the length of the liner's prepared edge joints (Fig. 14). High voltage spark testing was performed along all field welds (Fig. 15) to ensure that a watertight liner assembly was provided. In addition to the spark testing and visual inspections of the installed protective liner, testing requirements for the project included daily tensile testing of welded liner splice samples, plus tension and shear pull-testing of representative samples of the installed hooked reinforcement dowels (Fig. 16).

CONCLUSIONS

The repair and protection of concrete infrastructure in harsh environmental exposures can pose challenges for required restoration techniques and protection measures. The raw influent in wastewater treatment facilities produces significant concentrations of hazardous and corrosive gases and acids that can deteriorate concrete materials and metal components at a rapid rate. However, through appropriate pre-assessment of the existing infrastructure and an understanding of the exposure conditions and facility usage requirements, it is possible to successfully adapt and advance established concrete rehabilitation and protection principles in order to maximize the longevity and resiliency of existing WWTP concrete structures.

In an existing wastewater influent channel with significant deterioration and loss of concrete thickness at the roof and wall members, the construction of a new bonded concrete overlay with integral HDPE protective liner assembly was successfully achieved (Fig. 17) to restore and enhance the channel's load-carrying capacity, and to provide appropriate long-term protection against harsh environmental exposures in the future. The date of substantial project completion was May 25, 2015.

REFERENCES

1. ICRI Committee 310, "Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair (ICRI 310.2R-2013)," International Concrete Repair Institute, St. Paul, MN, 2013, 48 pp.

2. ACI Committee 350, "Code Requirements for Environmental Engineering Concrete Structures and Commentary (ACI 350R-06)," American Concrete Institute, Farmington Hills, Michigan, 2006, 387 pp.

3. NSF International Standard / American National Standard NSF/ANSI 61-2013 "Drinking Water System Components – Health Effects," NSF International, Ann Arbor, Michigan, 2013, 58 pp.

4. ACI Committee 562, "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings and Commentary (ACI 562-13)," American Concrete Institute, Farmington Hills, Michigan, 2013, 59 pp.

Fig. 14: Field welding of HDPE liner seams

Fig. 15: Spark testing of completed HDPE liner welds

Daryl Prefontaine*, BSc, MEng, LEED®AP, PE, is a Principal at Read Jones Christoffersen Ltd, in the Edmonton office's Building Science and Restoration group. He specializes in the evaluation and repair of concrete structures, and has over 25 years of experience in the design of new buildings and the restoration and protection of existing structures.*

He received his BSc in civil engineering in 1985 and Master of Engineering (structural) in 1995 from the University of Alberta, Edmonton, AB. Prefontaine is a member of ICRI and the American Concrete Institute (ACI), and has served on ICRI Committee 150, ICRI Notes on ACI 562 "Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings."

Fig. 16: Load testing of dowels

Fig. 17: Nearing completion of overlay and HDPE liner assembly at overflow wier

Gold Bar Influent Channel No. 2 Structural Repair

Edmonton, Alberta, Canada

OWNER
EPCOR Water Services Inc.
Edmonton, Alberta, Canada

STRUCTURAL ENGINEER
Read Jones Christoffersen Ltd.
Edmonton, Alberta, Canada

GENERAL CONTRACTOR
Sure-Form Contracting Ltd.
Edmonton, Alberta, Canada

MATERIAL SUPPLIERS
AGRU America Inc.
Georgetown, South Carolina

Sika Canada Inc.
Edmonton, Alberta, Canada