Calculating Corrosion

A cost-effective approach to evaluating hydrogen sulfide deterioration in a concrete interceptor

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The Shades Valley Transfer Line (SVT) in Jefferson County, Ala., is only 24 years old, but high hydrogen sulfide conditions early in its operation have its owners concerned about its overall condition. The Jefferson County Environmental Services Department (ESD) owns and operates the 92,000-ft (28,000-m) SVT as part of its 3100-mi (5000-km) collection system.

However, due to a limited budget, ESD robotically inspecting the entire 92,000 linear ft (28,000 linear m) of reinforced-concrete pipe was out of the question, so the agency sought an evaluation process that would identify the worst segments on the interceptor so that complete inspections could be limited to those segments.

The solution was a risk-based approach that uses a model to tie accepted equations for the production and release of hydrogen sulfide gas to the corrosion of the interceptor.

In the end, the model proved a useful tool and saved ESD $350,000 when compared to inspection of the entire line. The model also has the added value of providing hydraulic analyses of the SVT.

The Early Days of the SVT

The SVT, which varies from 4.5 ft (1.4 m) to 6.0 ft (1.8 m) in diameter, was constructed in 1986 to abandon the Shades Valley Wastewater Treatment Facility by pumping wastewater to the Valley Creek Wastewater Treatment Plant (see figure below). Shortly after construction, ESD became aware of significant levels of hydrogen sulfide corrosion that likely were due to high-strength industrial wastewater and pump-station force mains discharging into the line.

Manned inspections of one section of the interceptor in the late 1990s revealed dangerously corroded pipe, further reinforcing ESD's opinion that the entire interceptor was at risk of premature failure due to hydrogen sulfide deterioration.

Hydrogen sulfide is an odorous, toxic gas produced from domestic wastewater decomposition. Under certain conditions, the gas is generated and released into the air within the collection system. Once the hydrogen sulfide comes in contact with the exposed pipe surface — particularly the crown of the pipe — bacterial action causes it to oxidize quickly into sulfuric acid. The acid collects on the pipe surface and corrodes the pipe material.

ESD installed ventilation systems along the interceptor in 2002 to vent out the gas before it could damage the pipe and eliminated the high-strength discharges, but staff engineers harbored continuing concerns about the overall condition of the pipe.

Seeking the Problem Areas

To help identify where along the SVT to spend its inspection dollars, ESD used a risk-based approach to identify the highest-risk sewer segments. The risk-based approach was divided into four phases:

- Initial risk assessment.
- Preliminary investigations.
- Field investigations.
- Analysis and recommendations.

Initial Risk Assessment

The goal of the initial risk assessment for the SVT study was to identify, through an analysis of the SVT's physical characteristics, the line segments most likely to be suffering hydrogen sulfide attack.

This was accomplished with a dual analytical approach. The first approach was based on a "hands-on" review of pipe slope and wastewater flow to identify segments most likely to be generating hydrogen sulfide. The second approach consisted of the development of a wastewater corrosion model. Finally, using the data from both approaches, physical conditions known to exacerbate the release of hydrogen sulfide into the pipe atmosphere were factored in, leading to a list of high-risk segments.

The corrosion model was built on the MWH Soft (Arcadia, Calif.) InfoSWMM hydraulic modeling software, a geographical-information-system-based interface to the U.S. Environmental Protection Agency's SWMM 5.0 program. This program contains a corrosion-prediction module that uses quantitative methods developed to predict hydrogen sulfide buildup.

The corrosion model is driven by the biochemical oxygen demand concentrations in the flow stream and uses a series of input variables to mimic the processes that occur in sewer systems to convert biochemical oxygen demand to hydrogen sulfide and then to sulfuric acid. The model then estimates the annual average rate of corrosion, based on the concentrations and pipe material.

To construct the collection system model, developers used ESD's up-to-date database of its wastewater collection system showing the alignment of the system, as well as record drawings of the SVT, recent survey data of the manhole top

Shades Valley Transfer Line

TETRA TECH

The inspection contractor used a floating transport with closed-circuit television and sonar sensor technologies to inspect about 21,000 ft (6400 m) of the Shades Valley Transfer line. Track-mounted inspection equipment couldn't fit through the line's access structures.

elevations of the entire SVT, and flow and rainfall monitoring data for spring 2008.

Calibration of the hydraulic characteristics of the collection system model was accomplished using the flow and rainfall data provided to the modelers by ESD. The corrosion model, however, was calibrated using typical industry values, since no data had been obtained regarding the corrosive characteristics of the SVT. This yielded a preliminary list of segments with the highest probability of hydrogen sulfide corrosion. To this list were added segments deemed likely to be corroded, based on operator experience and engineering judgment.

Preliminary Investigation

With the results from the model in hand, Tetra Tech (Pasadena, Calif.) conducted preliminary field investigations to confirm the initial modeling results and to obtain specific information for use in more precisely calibrating the corrosion model. These investigations consisted of visual inspections of the pipe, sampling, monitoring, and testing for hydrogen sulfide gas and for wastewater characteristics conducive to the production of hydrogen sulfide gas. Testing was performed at intermittent manholes along the entire 92,000-ft (28,000-m) length of the SVT.

The visual inspections were performed with a pole-mounted camera to obtain video and photographic information of the condition of the SVT near the access structures. Concrete samples along the crown of pipe were obtained to evaluate the current state of corroded concrete. Atmospheric hydrogen sulfide levels in the interceptor were monitored, and the wastewater was sampled and tested to determine its characteristics. The wastewater characteristics data were used to recalibrate the corrosion model.

While the preliminary field investigations found corroded pipe, very little hydrogen sulfide gas was measured by the gas monitors. Furthermore, the characteristics of the wastewater indicated that very little hydrogen sulfide gas was being produced.

Previous hydrogen sulfide deterioration had been established by ESD's manned inspections, so the modeling team concluded that the existing corrosion had occurred under different conditions that existed early in the life of the project.

Fortunately, adequate data had been collected and archived substantiating the wastewater characteristics of the interceptor early in its life. Accordingly, these data were evaluated and used to revise the corrosion model calibration. The revised model predicted significant corrosion at multiple locations along the interceptor. Based on these revised modeling results, a detailed inspection plan was devised and implemented.

Schedule constraints pushed the preliminary investigations into early April 2008 — a time of year typically corresponding to lower hydrogen sulfide generation. Due to the absence of any hydrogen sulfide indicators, the team decided that a second round of monitoring and sampling should be conducted during the summer months, when hydrogen sulfide generation is typically at its peak.

These additional investigations were conducted in mid-September 2008. As expected, the September investigation detected higher levels of hydrogen sulfide in the interceptor headspace and wastewater characteristics more conducive to hydrogen sulfide generation. However, the levels measured were much lower than the historical rates that would have been necessary to produce the observed corrosion. This confirmed the team's hypothesis that the existing corrosion had occurred early in the life of the interceptor under different conditions than currently existed and that the ventilation system installed in 2002 is operating as designed to limit the buildup of hydrogen sulfide gas.

Detailed Internal Inspections

Based on the results of the preliminary investigation and the revised corrosion model, a detailed inspection plan was developed. The plan called for inspections of approximately 15% of the SVT's length by robotic equipment equipped with three different sensor technologies — closed-circuit television, sonar, and ground-penetrating radar. The plan was provided to the inspection contractor Pipe Eye International (Las Vegas), which determined that physical access to the interceptor was not possible for the equipment specified for the inspections.

Access limitations were largely due to the type of access structure constructed with the SVT. The access structures contained only a 30-in. (762-mm) opening at the entrance to the pipe. This did not provide sufficient clearance for the insertion of a tracked inspection vehicle. As a result, only a floating transport with closed-circuit television and sonar sensor technologies was feasible for the inspections. Due to the cost savings provided by the elimination of ground-penetrating radar, the extent of the inspections was increased to 23% of the system.

The inspection contractor used a float and sensor assembly to inspect approximately 21,000 ft (6400 m) of the SVT.

Each video segment was coded using the Pipeline Assessment Certification Program coding system, a national standard for grading sanitary sewer pipelines developed by the National Association of Sewer Service Companies (Owings Mills, Md.). It is often specified, as was the case here, as a requirement for pipeline inspection projects.

The inspection data were reviewed to grade each pipe segment according to its corrosion. A more-detailed grading system, emphasizing the extent and severity of reinforcing steel exposure, was devised to distinguish between different levels of pipe degradation.

Random internal inspections confirmed that segments excluded by the model were at minimal risk of hydrogen sulfide corrosion.

Model Validation

The detailed internal inspections demonstrated good correlation with the modeling results. For example, the worst segment of pipe observed during the visual inspections was found within 400 ft (122 m) of where the model predicted it would be. Furthermore, internal inspections were conducted 1700 ft (518 m) downstream and 5000 ft (1524 m) upstream of that section, and the observed corrosion diminished significantly, consistent with the results predicted by the corrosion model.

The results of the internal inspections validated the corrosion modeling and confirmed the team's hypothesis regarding existing corrosion rates.

Remaining Structural Life

With the corrosion model validated by field inspections, the Tetra Tech team set out to determine the remaining structural life of the SVT by segment and to prioritize repairs. Initially, a rating system based on the amount of exposed rebar in each segment was established to provide preliminary estimates of the remaining life expectancy of each segment. However, after further evaluation of the video inspection data, the approach for measuring degradation was changed to the average observed depth of concrete loss in a segment, in inches, based on observations made by the inspection subcontractor. This approach more accurately represented segments where the concrete had suffered deterioration but had no exposed reinforcing steel.

As constructed, the SVT had 1.75 in. (44.45 mm) of concrete cover over the inner layer of steel reinforcing. This inner steel ring provides tensile reinforcement of the pipe, and a compromise in the steel's strength could result in pipe collapse; therefore, for the purpose of this study, extensive exposure of the inner steel ring signals the end of the pipe's service life.

The observed average concrete loss in each segment was subtracted from the original 1.75 in. (44.45 mm) of cover to determine the remaining depth of concrete cover. In segments without TV inspection data, modeled corrosion rates for conditions prior to odor control and ventilation improvements in 2002 were used to estimate the remaining depth of cover.

Next, the current average corrosion rate for each segment was calculated by averaging the model predictions that were based on hydrogen sulfide and wastewater sampling conditions in April and in September.

The conditions modeled in April yielded virtually zero corrosion potential in all of the SVT. It is expected that the SVT experiences the same near-zero corrosion rates during the winter and spring months. The highest corrosion risk is in summer and fall. The September conditions produced higher corrosion rates than the April conditions but were much less than the average historical rates.

An average of the September and April rates was used to estimate the annual corrosion rate for each segment after 2002.

Finally, using the remaining cover depth and the average current corrosion rate, an urgency-of-repairs rating was determined for each segment. A rating system then was developed to describe the urgency of repair for each line segment and characterize its estimated remaining useful life.

Two recommendations related to the pipe structural life were provided. The first was to replace or rehabilitate eight line segments that were considered to be at risk of failure during the next 3- to 5-year period. The second was to install a simple, low-tech, low-maintenance corrosion-monitoring system consisting of 1.5-in. × 6-in. (38.1-mm × 152.4-mm) concrete blocks. The blocks would be measured prior to installation and subsequently retrieved and remeasured periodically.

Remaining Hydraulic Life

In addition to helping locate where to inspect for hydrogen sulfide deterioration, the model also provides insight into the hydraulic capacity of the SVT. The hydrologic–hydraulic model was calibrated to flow and level data collected at 13 monitoring locations, nine on the SVT and four located on larger tributary sewers. The calibration focused on flow monitoring performed from February through April 2008 and was supplemented with 4 years of historic data from permanent meters on the SVT.

The engineers used the model to perform a capacity analysis to evaluate the SVT hydraulic capacity, compared to current and future flow rates — that is, the number of years remaining until the pipe cannot handle the peak flow rates. The current and future flow rates are determined by running a theoretical design storm event through the hydraulic model.

A two-tier design storm event approach was selected for this project. Conveyance capacity was evaluated with a 2-year and 5-year, 3-hour-duration design storm event, and storage analysis was performed with a 2-year and 5-year, 24-hour-duration design storm event. Total rainfall depths were obtained from the *Rainfall Frequency Atlas of the United States* (Technical Paper No. 40) from the U.S. National Oceanic and Atmospheric Administration.

The useful hydraulic remaining life of the SVT is defined as the number of years predicted until the sewer does not have sufficient capacity to handle peak flow rates. This involves a comparison of the peak flow rates in the SVT to its capacity at different future conditions (*e.g.*, in 2015, 2020, and 2025).

The results indicated that under the operating conditions at the time, the SVT did not have sufficient capacity for current peak flow rates for both the 2-year and 5-year design storm events. This seems to indicate that most segments of the SVT have no hydraulic life remaining. This finding is evidenced with three known sanitary sewer overflow discharges from one of the SVT's manholes in 2006.

However, ESD and its contractors evaluated alternatives to provide relief for excess flows or equalization volume to store excess flows until capacity becomes available, or both. The cost-effective alternative was to modify flow management to the SVT in real time during flow events in combination with off-line storage. The storage was sized to maximize the existing SVT collection system and limit the amount of new sewer constructed.

Project Output

Through this project, the model developers and ESD determined that corrosion modeling adequately predicted the location of the most corroded reaches of the SVT. The prediction was sufficiently accurate to enable the internal inspections to be limited to the general location of the most highly corroded segments. A good next step would be to test these findings in other pipelines to determine whether the corrosion model proves to be as reliable in other contexts.

However, in this case, the model as implemented was found to be cost-effective and accurate. The model successfully excluded from consideration large portions of the SVT. Random internal inspections in these areas confirmed that these segments were at minimal risk of hydrogen sulfide corrosion. The risk-based approach saved approximately $350,000 over the cost of internally inspecting the entire SVT. Additionally, ESD received a calibrated hydraulic and corrosion model of the SVT, as well as estimates of remaining structural and hydraulic life of the SVT.

One final finding from the project: The internal inspections demonstrated a high degree of variability in the corrosion observed in contiguous segments. Accordingly, it can be concluded that extensively corroded pipe in one area does not necessarily indicate the same degree of corrosion throughout the interceptor.

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