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QUARTERLY REPORT

Guidelines for the Identification of Stress Corrosion Cracking Sites and the Estimation of Re-Inspection Intervals for Stress Corrosion Cracking Direct Assessment

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Prepared By:
Fraser King
Principle Investigator
NOVA Research & Technology Corporation
2928 16th Street, N.E.
Calgary Alberta T2E 7K7
fraser.king@shaw.ca

Scott Thetford
Team Project Manager and Technical Coordinator
Pipeline Research Council, International
1401 Wilson Blvd., Suite 1101
Arlington, VA 22209
703-387-0190
sthetford@prci.org

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PRCI LEADING PIPELINE RESEARCH
Pipeline Research Council International, Inc.
1401 Wilson Boulevard • Suite 1101 • Arlington, VA 22209 • USA
Main 703-387-0190 • Fax 703-387-0192 • www.prci.org

Project Background

The objective of this project is to develop a set of quantitative guidelines for predicting where and when Stress Corrosion Cracking (SCC) might be an integrity threat for gas and liquid hydrocarbon pipelines. These objectives will be achieved over 24 months through the following tasks:

- Task 1: Data Collection – Data will be collected from the literature, company or field records, pipeline operators, and regulators;
- Task 2: Data Analysis – Analysis of field and laboratory data to derive relationships describing susceptibility to SCC, crack initiation, crack growth and dormancy, and crack growth to failure;
- Task 3: Documentation – Document the results of the data analysis task;
- Task 4: Technology Transfer – Disseminate the results of this work to the industry; and
- Task 5: Administration and Reporting – Direct and document the research and report on project progress and results.

Technical Status

Progress in the quarter was made on a number of the scheduled tasks. In particular, progress was made on Task 1: Data Collection and Task 2: Data Analysis.

Task 1: Data Collection

Sub-task 1.1 Data Collection from Literature

Formal data collection from the historical literature has been completed and copies of more than 200 papers, reports, proceedings, and industry guidelines have been collected. This part of the data collection will continue throughout the project to capture publications appearing in the literature during the course of 2006-2008. The amount of new literature appearing during the course of the project is expected to be a small fraction of that available in the historical literature.

Sub-task 1.2 Data Collection from Pipeline Operators

This sub-task has been on-hold for the past two quarters because of a delay in the co-ordination of activities with other PRCI SCC projects. PRCI-member companies have requested that the data collection for this project be coordinated with that from other similar PRCI SCC projects in order to avoid multiple requests for the same data.

Progress was made in developing the format of the data questionnaire and this was communicated in the quarterly update in May 2007. However, since that time, the PRCI SCC data collection projects have not progressed and no data-call has yet gone out to pipeline companies. This issue will need to be resolved in the next quarter as time will be required to collect and analyze the data in time for validation of the guidelines developed from this work prior to project completion.

Sub-task 1.3 Data Collection: Foreign SCC Mitigation Practices

Collection of foreign SCC data was part of the overall coordinated strategy with PRCI. This task has been delayed because of the same issues with data collection from domestic pipeline companies.

This issue will also be addressed in the coming quarter.

Task 2: Data Analysis

Analysis of the data has been proceeding simultaneously with data collection.

Sub-task 2 Data Analysis: Categorizing Data

Categorization of the data involves reading the assembled literature and determining which stage of crack growth the results refer to. The four stages or modules of the guidelines are:

1. SCC susceptibility
2. Crack initiation
3. Crack growth and dormancy
4. Crack growth to failure

The major focus of this project is the development of guidelines based on an analysis of literature R&D SCC studies, with the conclusions validated by comparison with field data from operating pipeline companies.

The proportion of the data collected (or expected to be collected in the case of field data from operating companies) referring to each of the four categories differs for the two sources of data (R&D literature and field data). In the case of the R&D information, approximately equal proportions address the crack initiation, growth and dormancy, and growth-to-failure stages, with less information on SCC susceptibility. The proportion of information for each of the three major stages also differs for the two forms of external cracking; high-pH SCC and near-neutral pH SCC.

Table 1: Examples of Data Collected from the Technical R&D Literature for the Four Stages of Cracking and for the Two Forms of External SCC

Stage	High-pH SCC	Near-neutral pH SCC
SCC Susceptibility	Development of high-pH SCC conditions under disbonded coating Effect of CP on crack initiation (as it relates to locating high-pH SCC sites) Concentration and relative proportion of soluble and insoluble Effect of steel chemistry on crack initiation	Development of shielding conditions under disbonded coating Effect of CP on crack initiation Effect of water chemistry and pore-water CO_2 concentration on SCC initiation
Crack Initiation	Effect of potential on film formation and crack initiation Effect of CO_3^{2-}/HCO_3^- concentrations on passive film formation on C-steel Effect of maximum stress (σ_{MAX}) and stress magnitude (R value) on crack initiation	Effect of residual stress on crack distribution Effect of potential on crack initiation Effect of stress on crack initiation
Crack Growth and Dormancy	Dependency of dormancy on crack size and spacing within colony Effect of potential on crack growth Aspect ratio for high-pH SCC Analysis of SCADA pressure data	Aspect ratio for near-neutral pH SCC cracks Analysis of SCADA pressure data Conditions under which cracks decelerate during testing Interaction between colonies of shallow cracks
Crack Growth to Failure	Dissolution-based film-rupture models for crack growth Measurements of film-rupture strain to determine crack event frequency Measurement of film repassivation kinetics to determine extent of dissolution per crack event Aspect ratio for high-pH SCC Analysis of SCADA pressure data	Development of super-position crack growth models Development of corrosion fatigue models Effect of hydrogen on crack growth Aspect ratio for near-neutral pH SCC cracks Analysis of SCADA pressure data

Examples of the types and amounts of data for each of these stages and forms of cracking are given in Table 1. Information on high-pH SCC tends to come from the earlier literature, from the 1970's and early 1980's. At this time only one form of external SCC was recognized. High-pH SCC propagates by a film-rupture dissolution mechanism under certain specific environmental and electrochemical potential conditions. Thus, the relevant literature for high-pH SCC susceptibility is associated with the conditions under which a high-pH SCC environment might be formed on the pipe surface, especially as it relates to the type and condition of the coating.

The high-pH crack initiation literature includes studies on the effects of stress cycles (as characterized by the maximum stress and magnitude of the cycle (R value), temperature, potential, and solution composition.

Crack growth and dormancy studies include analyses of the distribution and spacing of cracks in different colonies, of the potential on crack growth rate and analysis of the aspect ratio of cracks.

Similarly, crack growth-to-failure studies include kinetic measurements used as input to crack growth models and for validation purposes. Thus, measurements of the rupture strain of crack-tip films, of repassivation kinetics, and of the frequency of crack rupture events have all been reported.

For near-neutral pH SCC, R&D studies that provide information about susceptibility include analyses of the effects of disbonded coating in shielding the pipe surface from CP and the effect of different groundwater species in the development of suitable trapped water environments. Crack initiation studies include measurements of the residual stress and the effects of potential and stress on initiation.

The study of crack growth for near-neutral pH SCC is an area of active research. Crack growth models are currently being developed that can be used to determine whether cracks are likely to become dormant, or whether they will grow to failure (see below). These models are based on either super-position principles or corrosion fatigue mechanisms.

Sub-task 2.1 Data Analysis: Pipeline Susceptibility to SCC

As noted above, much of the information gathered from the literature is relevant for determining conditions under which pipelines may be susceptible to SCC. Work in the last quarter has focused on crack growth and dormancy and crack-growth-to-failure.

Sub-task 2.2 Data Analysis: Initiation

As noted above, much of the information gathered from the literature is relevant for characterizing SCC initiation. Work in the last quarter has focused on crack growth and dormancy and crack-growth-to-failure.

Sub-task 2.3 Data Analysis: Crack Growth and Dormancy

Many of the models reviewed this quarter relate to both crack growth and dormancy and crack-growth-to-failure. Consequently, these models are reviewed together in the next section.

Sub-task 2.4 Data Analysis: Crack Growth to Failure

The development of crack growth models for near-neutral pH SCC is an area of active research. These models tend to be either of the super-position kind or corrosion fatigue based. In super-position modeling, mathematical expressions for two different types of process are combined (often by simply adding them together) to produce a combined expression that accounts for both mechanisms of crack growth. For example, Equation (1) is a super-position model for fatigue plus SCC under constant load

$$\left.\frac{da}{dN}\right|_{total} = \left.\frac{da}{dN}\right|_{fatigue} + \frac{1}{f}\left.\frac{da}{dt}\right|_{SCC} = C \cdot \Delta K^{m} + \frac{1}{f}\left.\frac{da}{dt}\right|_{SCC} \qquad (1)$$

due to Lambert and co-workers. Alternatively, corrosion fatigue models are used to account for the synergistic effects of fatigue and corrosion, and are typically of the form (Been et al., IPC2006-10345)

$$\left.\frac{da}{dN}\right|_{total} = \left.\frac{da}{dN}\right|_{corrosion\ fatigue} = C_{cf} \cdot \Delta K^{m_{cf}} \qquad (2)$$

The choice between the two types of model is generally determined by fitting laboratory crack growth data to one or more of these mathematical expressions.

Plans for Future Activity

The following activities are anticipated for the next milestone period:

Technical Progress

The project will work on the further reading of literature data and development of guidelines for each module or stage of the guidelines. The focus will especially be on SCC susceptibility and crack initiation.

Additionally, the team will further development of guidelines for crack growth and dormancy and crack-growth-to-failure modules.

Progress on coordinated data collection from PRCI-member companies will continue.

Meeting and Presentations

None planned

Tests and Demonstrations

No tests or demonstrations are planned for the next reporting period.