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QUARTERLY REPORT
GTI PROJECT NUMBER 21874

Characterization and Fitness for Service of Corroded Cast Iron Pipe

Contract Number: DTPH56-15-T-00006

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Project Objective

Gas Technology Institute's (GTI) objective in this project is to

- Provide a Fitness-For-Service (FFS) model and method for operators to characterize and grade graphitic corrosion defects on cast iron natural gas pipes. This will help operators make monitoring, repair, and replacement decisions, as well as prioritize accelerated replacement decisions related to cast iron mains and services.
- Summarize and categorize the required input parameters to the FFS model related to cast iron material, graphitic corrosion geometry and characteristics, and operational environment.
- Validate the FFS model by comparing its output to a statistically analyzed set of historical cast iron failure data.
- Provide a physical testing program to fully validate the FFS model.

Executive Summary

The project was initiated this quarter with the kick off call being held on October 29, 2015. The TAP was formed and a call to review the scope was held on December 15, 2015. During this quarter GTI commenced the Task 2 literature search. The objective of this task is to conduct an in depth literature review on cast iron and cast iron piping materials. This will include the types of cast iron, flake morphology, changes in production method and properties over time, and ranges of physical and mechanical properties.

GTI also commenced the Task 3 historical cast iron failure data collection and analysis. We have requested company specific data from the TAP and already collected an initial set of cast iron field inspections from one operator.

Funds and Work Completed this Quarter (9/1/15 – 12/31/15)

Work Completed

Task 1. Form Technical Advisory Panel (TAP) – During this quarter GTI scheduled and completed the project kickoff meeting with DOT/PHMSA on October 29, 2015, and also formed the TAP and held a kick off meeting December 15, 2015. The presentation used for both the meetings is included in this report. The minutes from the TAP meeting are also included.

Task 2. Cast Iron Materials Literature Search – During this quarter GTI commenced the Task 2 literature search. So far, GTI has identified and collected 31 peer reviewed papers applicable to the project, as well as over a dozen additional technical resources such as books, reports, and data compilations.

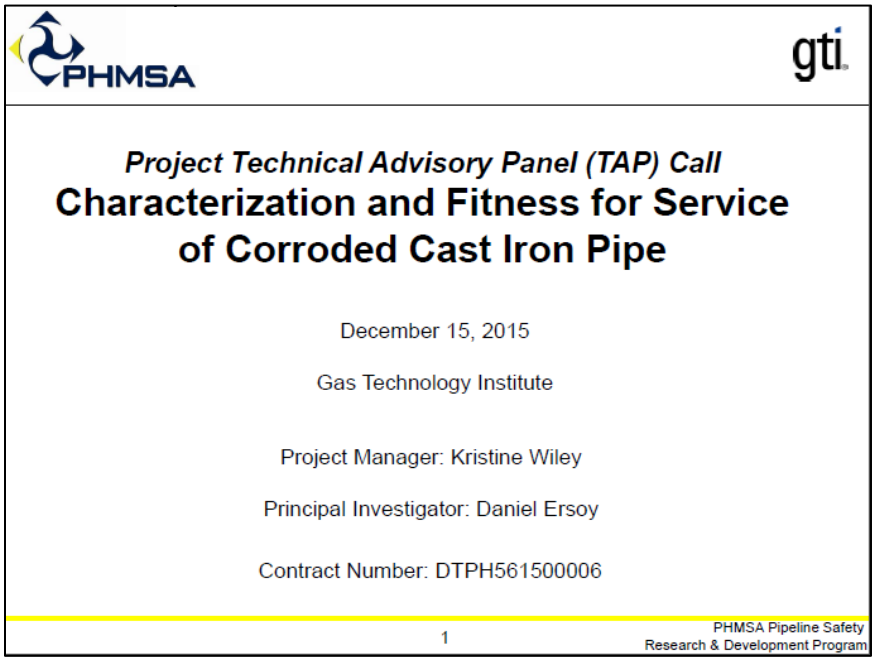
Task 3. Historical Cast Iron Failures Statistical Analysis – At the end of this quarter GTI commenced the Task 3 historical data collection and analysis. We have requested data from the TAP and already collected an initial set of cast iron field inspections from one operator.

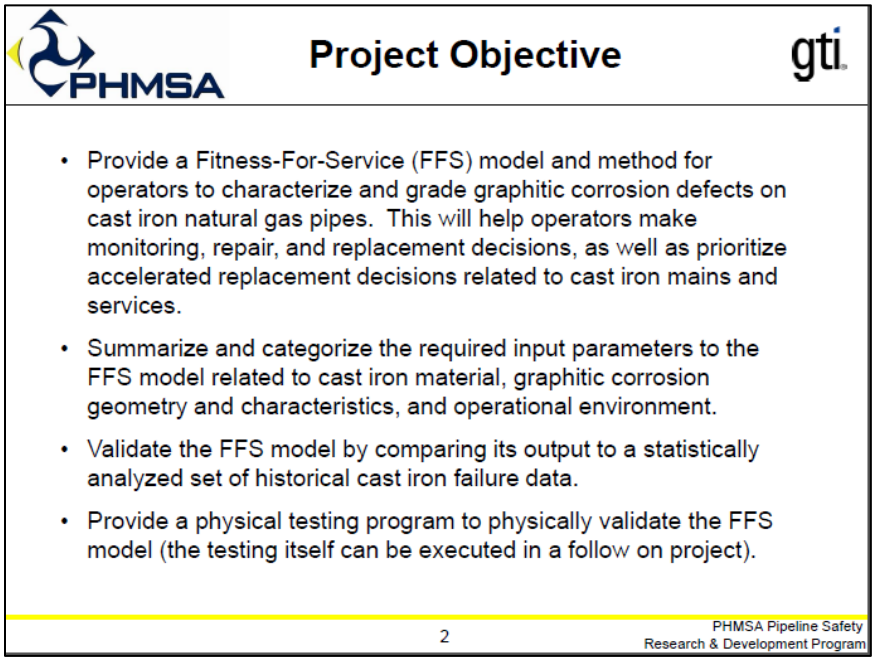
Technical Status

Activity: Task 1 - Form Technical Advisory Panel (TAP)

The project kickoff meeting was held with GTI and DOT/PHMSA on October 29, 2015. This is a project deliverable due at Month 1 of the project. The participants included: Kristine Wiley/GTI, Daniel Ersoy/GTI, and Chris McLaren/DOT PHMSA.

The materials for the meeting are shown below. The same presentation materials were used for this Oct. 29, 2015 meeting and the Dec. 15, 2015 TAP meeting so the later one is presented below since it has a slightly updated TAP member slide.





Project Tasks
Task 1 - Form Technical Advisory Panel (TAP)
Task 2 - Cast Iron Materials Literature Search
Task 3 - Historical Cast Iron Failures Statistical Analysis
Task 4 - Finite Element Analysis of Failure Modes
Task 5 - Characterize Graphitic Corrosion Severity
Task 6 - FFS Model of Characterized Graphitic Corrosion
Task 7 - Comparison of FFS Model with Field Failure Data
Task 8 - Develop Physical Testing Validation Program
Task 9 - Final Report
Task 10 - Project Management

Task 1 Technical Advisory Panel

- Members
  - Richard Trieste, Manager - Research and Development, ConEdison of New York, NY,
  - Bob Gardner, Director - Quality Assurance & Compliance, Alabama Gas, AL,
  - Kevin Murphy, Director- Operations, Planning and Measurements, Washington Gas, Washington D.C., and
  - Mary Holzmann, Principal - Gas Research and Development, National Grid, NY.
  - George Ragula, Distribution Technology Manager, Public Service Electric and Gas Company
- GTI is also seeking additional members from
  - UGI,
  - Integrys, and
  - Nicor

Project 21874 – Characterization and Fitness-For-Service (FFS) for Cast Iron (CI) Pipe

T1 – Form TAP Kickoff Project
Kickoff Meeting Minutes (1m)
TAP Scope Review (3m)

T2 – Materials Lit. Search
Stress-Strain Curves, Toughness, Modulus, Microstructure, etc.
Lit Rev Summary Report (5m)

T3 – CI Failures Historical/ Statistical Analysis
Root Cause, Defect Size, Materials, Loading
Summary Report (12m)

T4 – External Loading
Soil Burden, Settlement, Frost, etc.
Loading Tables for FEA (5m)

T4 – FEA/Stress Analysis
Design Document (9m)
Summary Report of Model (14m)

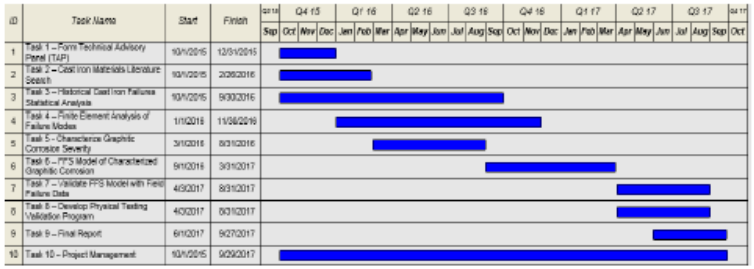
T5 – Characterization of Graphitic Corrosion
Define Geometry for Stress Concentrators
Depth, Aspect Ratio, Rotation
Guidance Characterization Document (11m)

T6 – FFS Model for Graphitic Corrosion
Inputs: Strength, Field Loading, Defect Geometry (depth, aspect, and rotation)
Model Report and Tables (18m)

T7 – Compare FFS Model with Failure Data
Validation Report (23m)

T8 – Develop Physical Testing Program
Testing Program Plan (23m)

T9 – Reports
Draft and Final Reports (23m)



ID	Task Name	Start	Finish
1	Task 1 – Form Technical Advisory Panel (TAP)	10/1/2015	12/31/2015
2	Task 2 – Cast Iron Materials Literature Search	10/1/2015	2/26/2016
3	Task 3 – Historical Cast Iron Failures Statistical Analysis	10/1/2015	9/30/2016
4	Task 4 – Finite Element Analysis of Failure Modes	1/1/2016	11/30/2016
5	Task 5 – Characterize Graphitic Corrosion Severity	3/1/2016	8/31/2016
6	Task 6 – FFS Model of Characterized Graphitic Corrosion	9/1/2016	3/31/2017
7	Task 7 – Validate FFS Model with Field Failure Data	4/3/2017	8/31/2017
8	Task 8 – Develop Physical Testing Validation Program	4/3/2017	8/31/2017
9	Task 9 – Final Report	6/1/2017	9/27/2017
10	Task 10 – Project Management	10/1/2015	9/29/2017

Notes

1. Inputs to the model from the field will be strength, defect geometry, and environmental characteristics.

2. Conservative defaults will be used if input values are unknown.

3. Output of the FFS model will be the proximity to failure with an associate confidence interval; this will be categorized by %of strength limit.

Task 2 Cast Iron Materials Literature Search

- Literature search will include
  - Types of cast iron, flake morphology, changes in production method and properties over time, and ranges of physical and mechanical properties,
  - Cataloging the variability of cast iron, which is much greater than API 5L pipeline steels, and
  - Canadian and British cast iron studies on water pipe, especially the failure mechanisms and damage characterization.
- Develop a list of tests that will be required for piping in the field to properly categorize the: cast iron type, flake size, wall thickness, chemistry, microstructure, etc.

Task 3 Historical Cast Iron Failures Statistical Analysis

- Investigate relationships between material, defect size and type, and operational variables and failure rates
- Focus will be placed on the type of graphitic corrosion and its: severity, extent, and distribution that lead to failure.

Task 4 Finite Element Analysis of Failure Modes

- FEA will be conducted to model the failure of cast iron piping systems with graphitic corrosion defects.
- Modeling will be used to determine the critical defect size and characteristics that could lead to premature piping failure.
- Considerations include: strength of the pipe and the graphitic layer left behind from graphitic corrosion; loading; hoop stress; thermal stress; and defect geometry, aspect ratio, and distance along the pipe axis.
- Develop a method to reduce a nearly infinite number of defect geometries, load cases, and material attributes to a tractable number of (respective) categories to allow for a straightforward application of the FFS model based on operator input data.

Task 5 Characterize Graphitic Corrosion Severity

- Develop a set of guidelines an operator will use to characterize the type and severity of graphitic corrosion on a cast iron pipeline in the field.
- This will allow the operator to consistently develop part of the input data needed to run the FFS cast iron model.

Task 6 FFS Model of Characterized Graphitic Corrosion

- This is the core deliverable of the project.
- The model will use operator inputs of the categorized cast iron pipe materials and properties, as well as the severity and extent of the graphitic corrosion, and the operational environment.
- The output of the model will be a quantitative assessment of the integrity risk of the corrosion damage on the particular cast iron pipe in the particular operational environment.

Task 7 Comparison of FFS Model with Field Failure Data

- Statistically analyzed cast iron field failures summarized in Task 3 will be compared against the Task 6 model results applied to the same situations.
- This is considered a first pass validation of the FFS model.

Task 8 Develop Physical Testing Validation Program

- Develop a physical testing validation program to validate the FFS model which would reinforce the validation from Task 7.
- Tests will include pressure tests on cast iron pipe samples and tensile and/or flexural tests on axial and longitudinal coupons.

Deliverables and Milestones

Activity	Completion Date (from Agreement)	Milestone/Deliverable
Task 1 - Form Technical Advisory Panel (TAP)	Month 3	Interim Report: TAP Scope Review and Feedback
Task 2 - Cast Iron Materials Literature Search	Month 5	Interim Report: Literature Review Summary for Critical Materials Properties
Task 3 - Historical Cast Iron Failures Statistical Analysis	Month 12	Interim Report: Statistical Summary Report of Cast Iron Failures and Key Variables
Task 4 - Finite Element Analysis of Failure Modes	Month 9 Month 14	Interim Reports: (1) FEA Design Document; (2) Summary Report of FEA Results
Task 5 - Characterize Graphitic Corrosion Severity	Month 11	Interim Report: Guidance Document on How to Characterize Graphitic Corrosion
Task 6 - FFS Model of Characterized Graphitic Corrosion	Month 18	Interim Report: FFS Model for Cast Iron Graphitic Corrosion
Task 7 - Comparison of FFS Model with Field Failure Data	Month 23	Interim Report: FFS Model Validation with Statistical Analysis of Cast Iron Failures
Task 8 - Develop Physical Testing Validation Program	Month 23	Interim Report: A Suggested Physical Testing Program to Fully Validate and Refine the FFS Model
Task 9 - Final Report	Month 23 Month 24	Draft and Final Reports
Task 10 - Project Management	Duration of the project	Ongoing: Monthly Updates, Quarterly Reports, Peer Reviews, and Public Presentation/Paper

As part of Task 1, GTI formed the project TAP with the following members:

- Richard Trieste, Manager - Research and Development, ConEdison of New York, NY,
- Bob Gardner, Director - Quality Assurance & Compliance, Alabama Gas, AL,
- Kevin Murphy, Director- Operations, Planning and Measurements, Washington Gas, Washington D.C.
- Mary Holzmann, Principal - Gas Research and Development, National Grid, NY and
- George Ragula, Distribution Technology Manager, Public Service Electric and Gas Company.

GTI is also working on adding a TAP member form Integrys and has requested the same from UGI and Nicor.

GTI scheduled and completed the TAP kickoff meeting on December 15, 2015. The same slides used with the GTI-DOT/PHMSA meeting on October 29, 2015 were used. This is a project deliverable due at Month 3 of the project.

The minutes of the December 15, 2015 meeting are presented below.

MEETING MINUTES

TECHNICAL ADVISORY PANEL CALL #1
December 15, 2015
10:00AM CENTRAL

CONFERENCE CALL NUMBER:
877-691-9300
Code: 7680910

DTPH561500006 Characterization and Fitness for Service of Corroded Cast Iron Pipe

***GTI Project Manager*: Kristine Wiley**
***GTI Principal Investigator:* Daniel Ersoy**

- Participants: Kristine Wiley/GTI, Daniel Ersoy/GTI, Khalid Farrag/GTI, Brian Miller/GTI, Oren Lever/GTI, Chris McLaren/DOT PHMSA, Kevin Murphy/Washington Gas, George Ragula/PSE&G, Mary Holzmann/National Grid, Rick Trieste/ConEd
- Provided overview slides of project
- Kristine and Dan presented slide deck, reviewed project objective as well as each project task
- Chris emphasized the importance of including operational environment when developing the fitness for service model
- Model inputs would include material properties, extent of graphitic corrosion and operational environment
- Model will calculate a quantitative risk and will not normalize or weight inputs

- Model will use default values if operators do not have information available
    - George cautioned the use of default values and how those will be determined
    - Dan recommended once the process for determining default values has been developed and values establish we have a call with the TAP to discuss and get their feedback
- George suggested we leverage extensive work that has been done on soil conditions as this should also be a key parameter in the model
- George also emphasized importance of breakage history and its importance in CI main replacement prioritization, this should be considered when developing the model
- Rick requested clarification on the definition of a failure. This project will focus on mechanical failures and will utilize yield strength to quantify proximity to failure
- Kevin asked how this model would be used when it comes to making decisions regarding replacement
    - The model will include uncertainty of parameters and will provide a quantitative output with an associated confidence interval based on the % of strength limit that will provide the operator with a proximity to failure. The operator can use this information to decide if a replacement is needed.

End of Meeting Minutes

Activity: Task 2 - Cast Iron Materials Literature Search

During this quarter GTI commenced the Task 2 literature search. We have identified 31 peer reviewed papers applicable to the project, as well as over a dozen additional technical resources such as books, reports, and data compilations. This work activity is ongoing.

Activity: Task 3 - Historical Cast Iron Failures Statistical Analysis

At the end of this quarter GTI commenced the Task 3 historical data collection and analysis. We have requested data from the TAP and already collected an initial set of cast iron field inspections from one operator. This work activity is ongoing.

Plans for Future Activity (Project Quarter #2)

The planned activities for the 2nd Quarter are:

- Continue with Task 2 Literature Search and organize the papers and other resources into groups with a table of abstracts and comments. The pertinent data and information from the Task 2 activities will be fed into the Task 4 Stress Analysis and the Task 5 Characterization of Graphitic Corrosion.
- Develop a list of tests that will be required for pipe categorization in the field.
- Deliver Interim Report: Literature Review Summary for Critical Materials Properties – Task 2 due at Month 5 of the project.
- Continue Task 3 work on Historical Cast Iron Failures and Statistical Analysis.

- Commence Task 4 Finite Element Analysis of Failure Modes
- Submit monthly reports