FIFTH QUARTERLY REPORT

DTPH56-14-H-00008
"Definition of Geotechnical and Operational Load Effects on Pipeline Anomalies"

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2.0 Technical Status

2.1 Technical Progress

Task 1: - Project Kickoff

The meeting discussion and actions were documented in meeting minutes posted to the project website.

Task 2: Documentation of Model Validation

The project team completed preparation of the model validation report from previous work describing the numerical model that will support this project and its capabilities as simulation tool. The report was submitted and posted to the project website.

Task 3: Model Development and Demonstration

Objective: Describe and demonstrate the simulation process to support discussion and confirmation of the project scope of work.

Scope: The scope of this task was to complete three subsidence and three lateral soil movement simulations with differing pipe geometries, soils, materials and operating conditions to illustrate the impact of the problem parameters on the analysis results.

Activities:

The completed report describing the geotechnical simulation process and results of three subsidence and three lateral soil movement simulations was posted to the DOT website. The results of the finite element analyses were interpolated, to produce an envelope defining the combination of ground displacement and width where the pipe was safe and not safe. Failure of "not safe pipe" was presumed to occur if the axial (tensile and/or compressive strains) at any location exceeded strain limit defined from BS 7910, CSA-Z662 and PRCI 2004.

Advisory Panel and the Analysis Results: In order to be able to react and confirm the project scope of work, an Advisory Panel meeting was held on April 6, 2015 to discuss the results and observations available at this time.

A presentation was made by BMT which was used as the basis for discussion. The presentation included the purpose of the Advisory Panel meeting, the objective of the project, deliverables and goals, the project plan and communication plan.

The meeting discussion and action were documented in meeting minutes by BMT and circulated for comment prior to posting to the DOT website

The meeting included invitees from:

- Julie Halliday –U.S. Department of Transportation Pipeline and Hazardous Materials Administration
- Zaid Obeidi –U.S. Department of Transportation Pipeline and Hazardous Materials Administration
- Colin Dooley –Alliance Pipeline
- Tammy Moore –Williams NWP
- Mike Hill –Enbridge Pipelines
- Nader Yoosef-Ghodsi –Enbridge Pipelines
- Aaron Dinovitzer – BMT Fleet Technology Ltd (BMT).
- Rick Gailing – BMT Fleet Technology Ltd (BMT).
- Abdelfettah Fredj – BMT Fleet Technology Ltd (BMT).

Mr. Doug Dewar (Spectra Energy) will also participate on the Advisory Panel but had to send his regrets for the recent meeting due to conflicting commitments.

Task 4: Modeling of Subsidence Hazard

Objective: Complete a sensitivity study to define the relationship between problem parameters and the pipe strains developed in soil subsidence events and identify trends.

Scope: The scope of this task is to develop and simulate a range of pipe soil subsidence scenarios considering differing pipe geometries, soils, pipe materials and operating conditions to define the impact of the problem parameters (e.g., depth of subsidence, subsidence length, surcharge) on the analysis results. It is expected that the modeling process will describe pipeline response in terms of axial and bending stresses and strains (or loads), pipe deformation and potential for buckling/wrinkling. These sample modeling results will be used to develop an empirical relationship between the pipe, pipeline, geotechnical and operating parameters affecting peak pipe strains.

Activities:

A sensitivity analysis is being carried out to evaluate the effects of the some key parameters, including:

- Pipe diameters and wall thickness or D/t ratio: 30”/0.5”=60, 30”/0.375=80, 30”/0.312=96, 24”/0.25”=96
- Pipe Grade: X52 and X70
- Subsidence Widths: Subcritical, critical and supercritical
- Subsidence: Pit Subsidence and Sag subsidence

Sample Results:

Sag Subsidence:

- Figure 2 shows an example of predicted subsidence basin along the pipeline for critical subsidence width. This subsidence results in axial soil movement and strains in the soil.

- Figure 3 through 5 plot the surface subsidence profile, pipeline profile and pipeline axial strains distribution at different clock position (3, 6 and 12 o'clock) along the length of the pipeline. The results presented in these Figures are for 30-inch pipe, with D/t ratio of 96 and material grade X52 considering subcritical, critical and Super-critical extraction width (W/H ratio of 0.75, 1.5 and 3).
- Figure 4 shows an example the axial tensile strains envelope for the 30-inch pipe, with D/t ratio of 96 and material grade X52 as a function of the panel width to mining depth ratio (W/H).

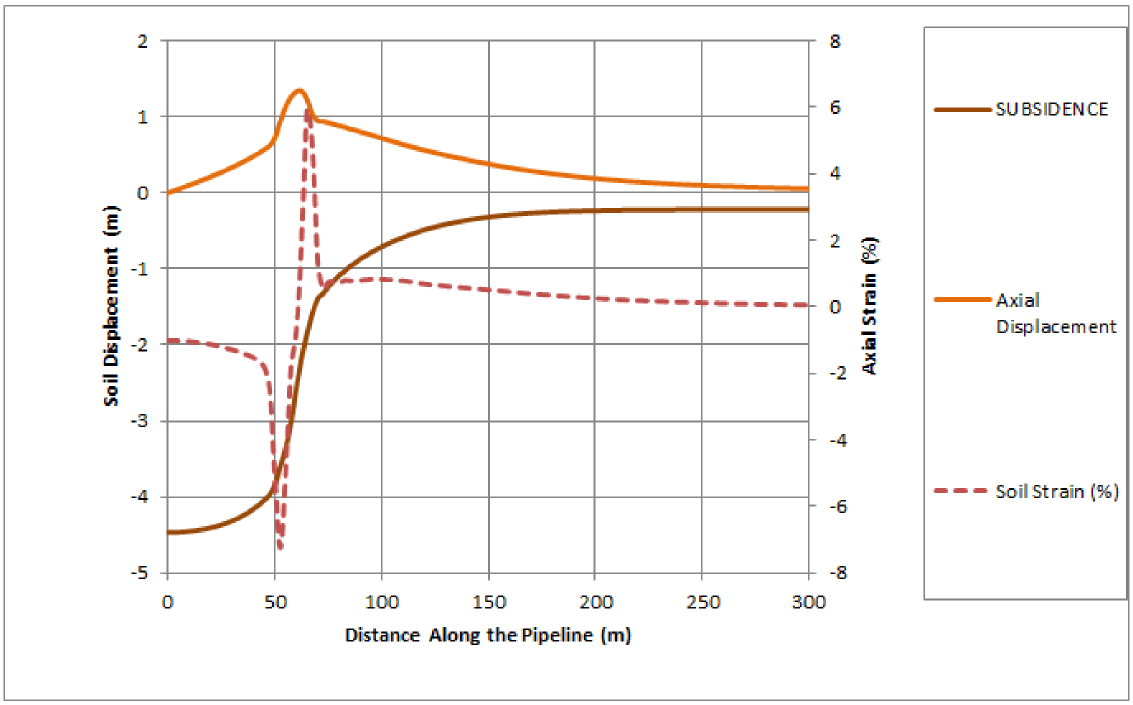

Figure 2: Predicted Subsidence Profile along the Pipeline and Maximum Axial soil displacement and Tensile Strains in the Soil

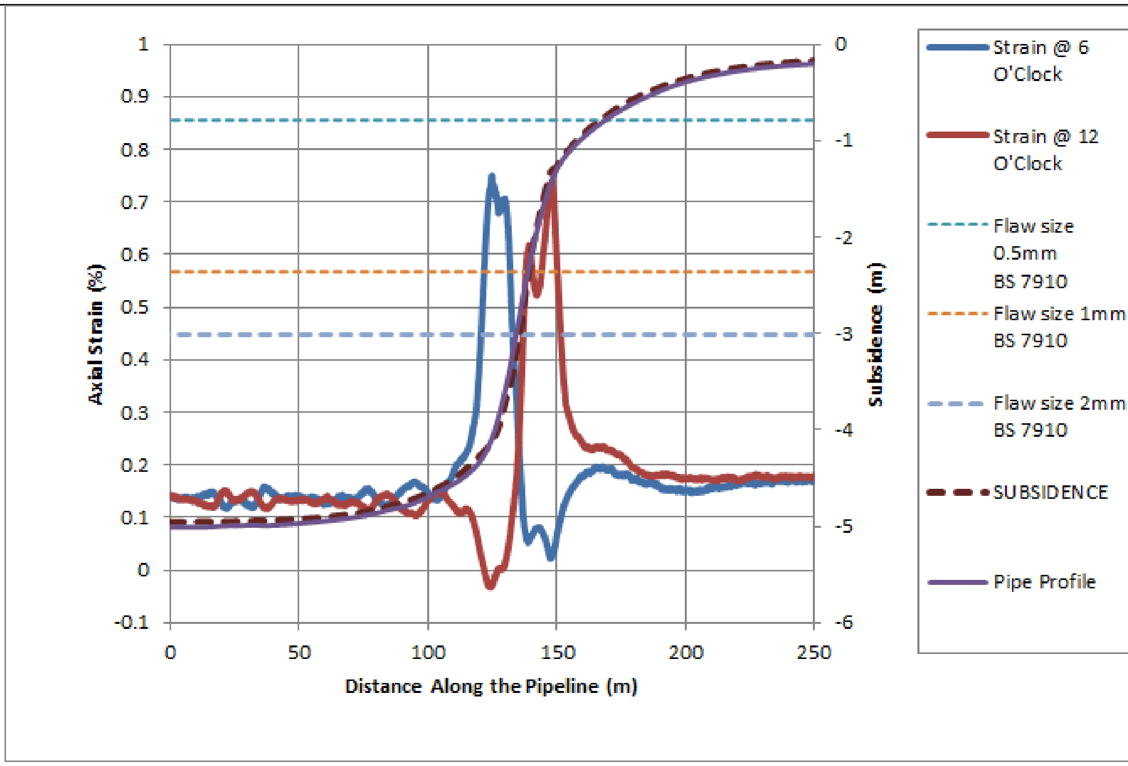

Figure 3: Predicted Pipeline, Subsidence Profiles and Maximum Tensile Strains in the Pipe in for Mining Depth Ratio (W/H=3)

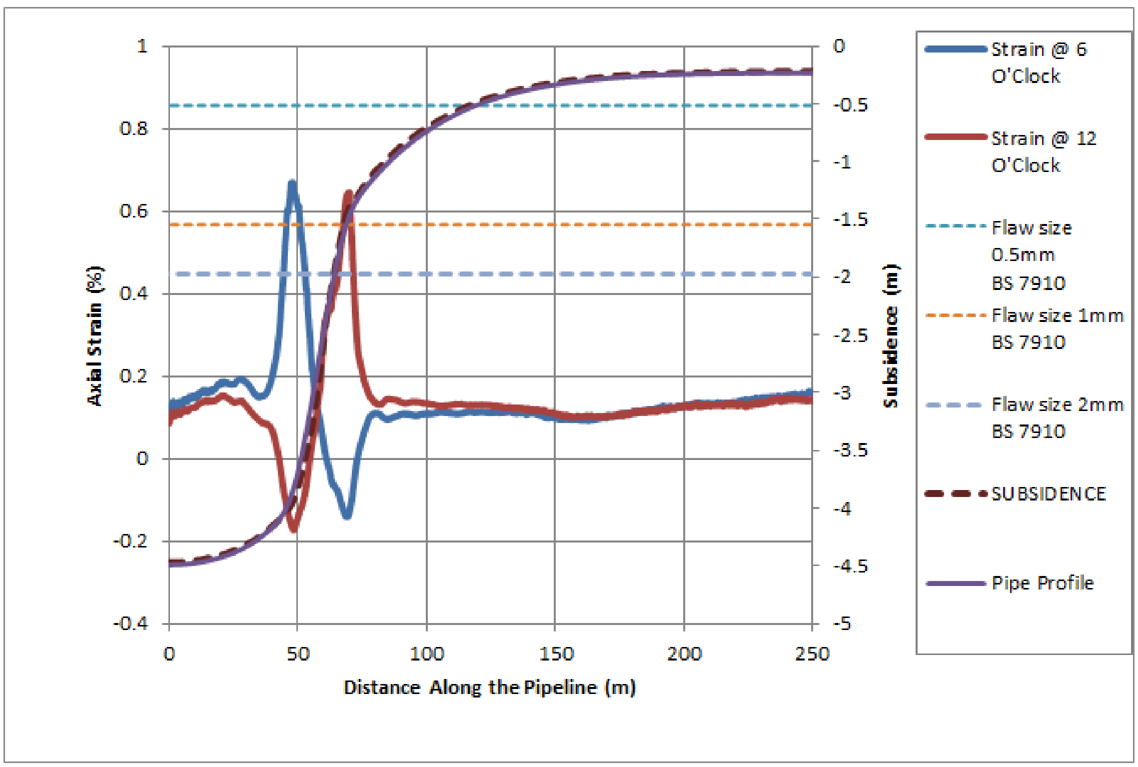

Figure 4: Predicted Pipeline, Subsidence Profiles and Maximum Tensile Strains in the Pipe in for Mining Depth Ratio (W/H=1.5)

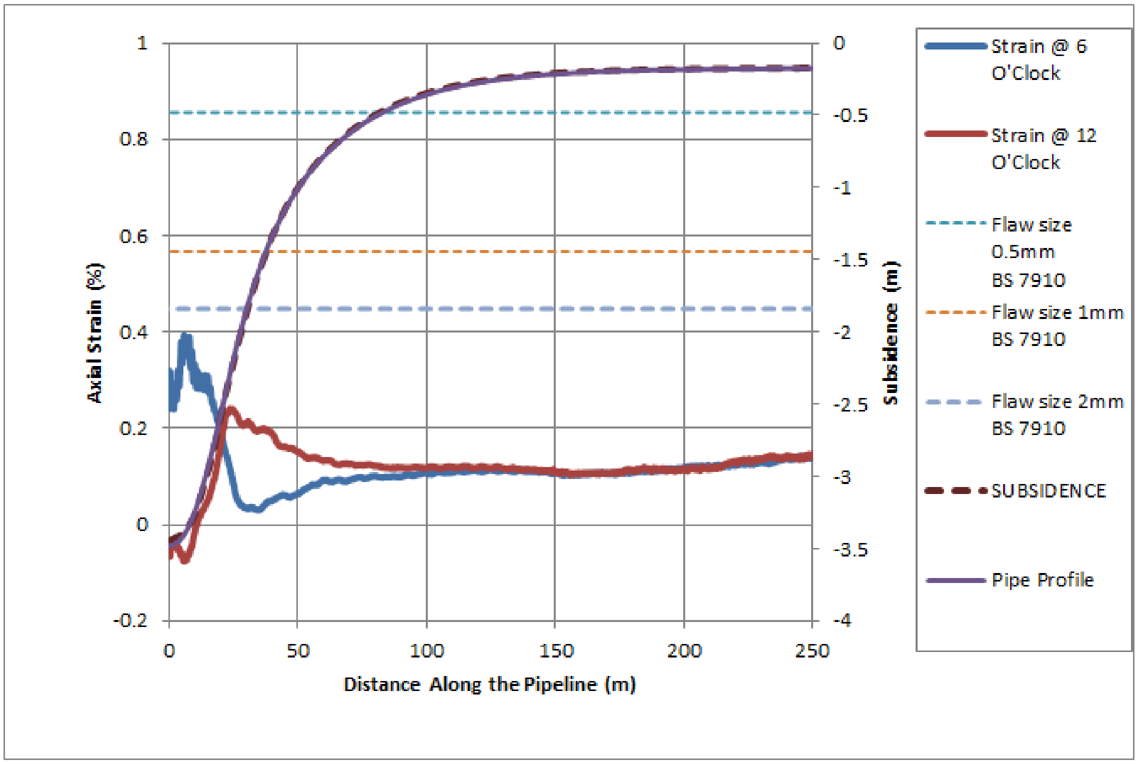

Figure 5: Predicted Pipeline, Subsidence Profiles and Maximum Tensile Strains in the Pipe in for Mining Depth Ratio (W/H=0.75)

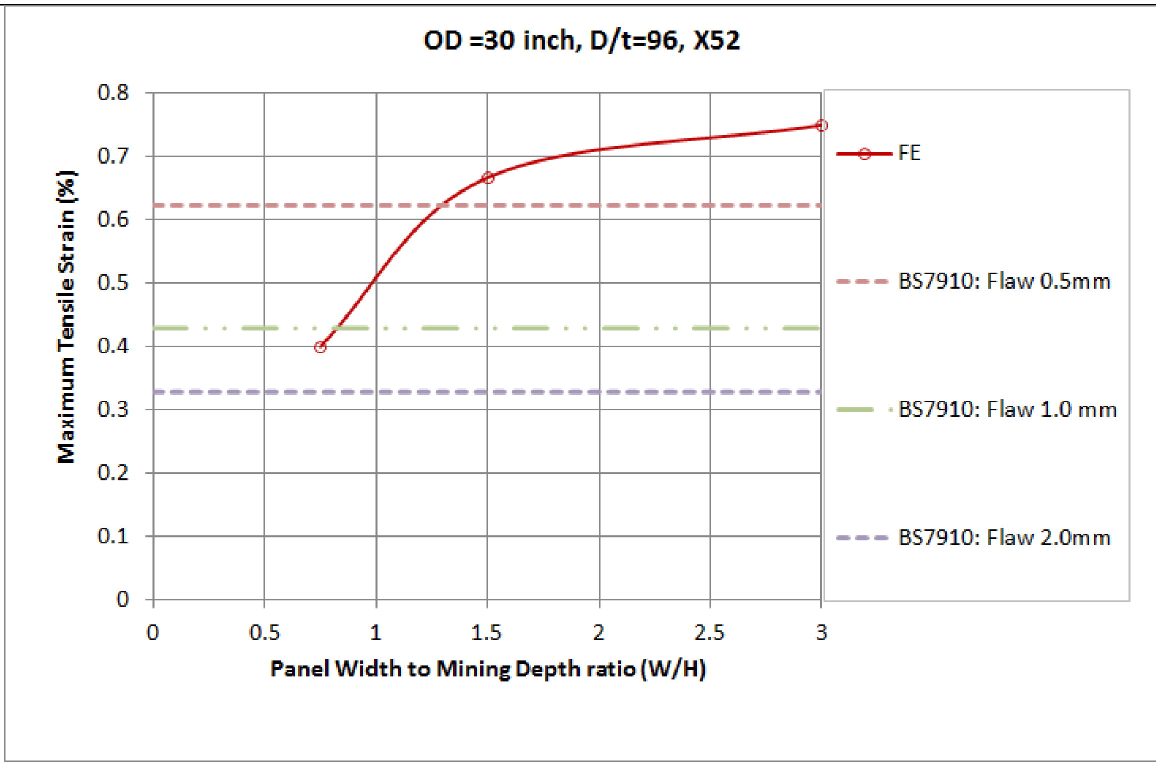

Figure 6: Maximum Tensile Strains in the Pipe in Relation to Panel Width to Mining Depth Ratio (W/H)

Pit Subsidence:

Pit subsidence is a circular hole in the ground with a diameter ranging from 1 to 20m, generally occurs over shallow mines, depth less than 50 m. The Analyses were completed for the 30-inch with D/t ratio of 96 to assess its response to pit subsidence considering a large pit diameter of 20m. Note that the focus of the project is sag subsidence. The Project Team will run some cases considering two pit diameters to demonstrate the significance of these geotechnical hazard events.

- Figure 7 shows an example of predicted Pit subsidence, where the pipeline experiences the adhesive resistance from the surrounding soil in addition to the weight of the soil above.

- Figure 8 plot pipeline profile and axial strains distribution at different clock position (6 and 12 o'clock) along the length of the pipeline. The results indicated that the tensile strains are higher than to 2% and the peak compressive strain was close to 0.5% for this analyzed case.

- Figure 9 and Figure 10 plot the pipe vertical displacement and peak tensile in pipe in relation to subsidence. The results clearly indicate that the pipeline response to pit subsidence is fairly complex and cyclic. The pipe in the mid plane settles to transfer the load from weight of the soil above and the soil resistance from the surrounding soil. However as the soil surrounding soil start to move "fall" around the pipe, the pipe start to rebound and covers about 17% of its vertical deflection, for the analyzed case.

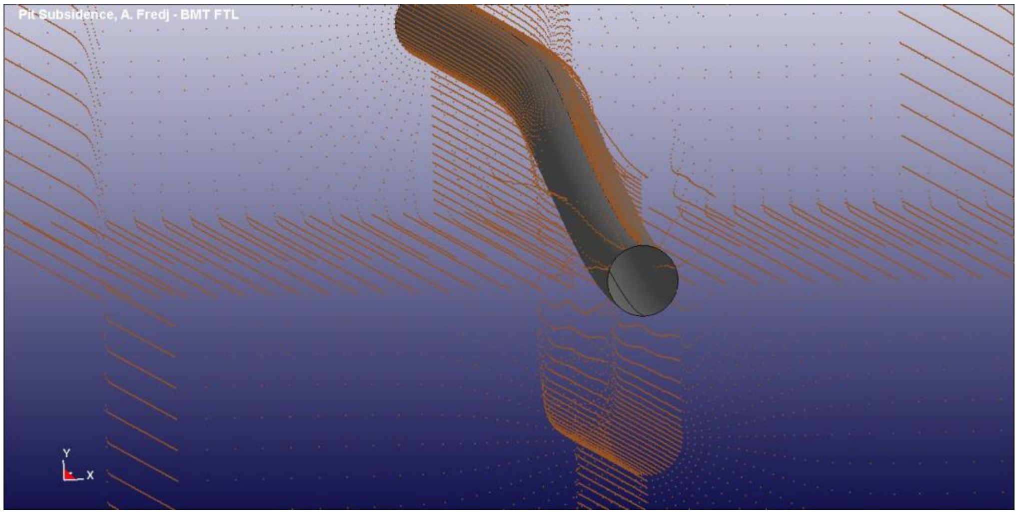

Figure 7: Pit Subsidence – Pipe Deflection

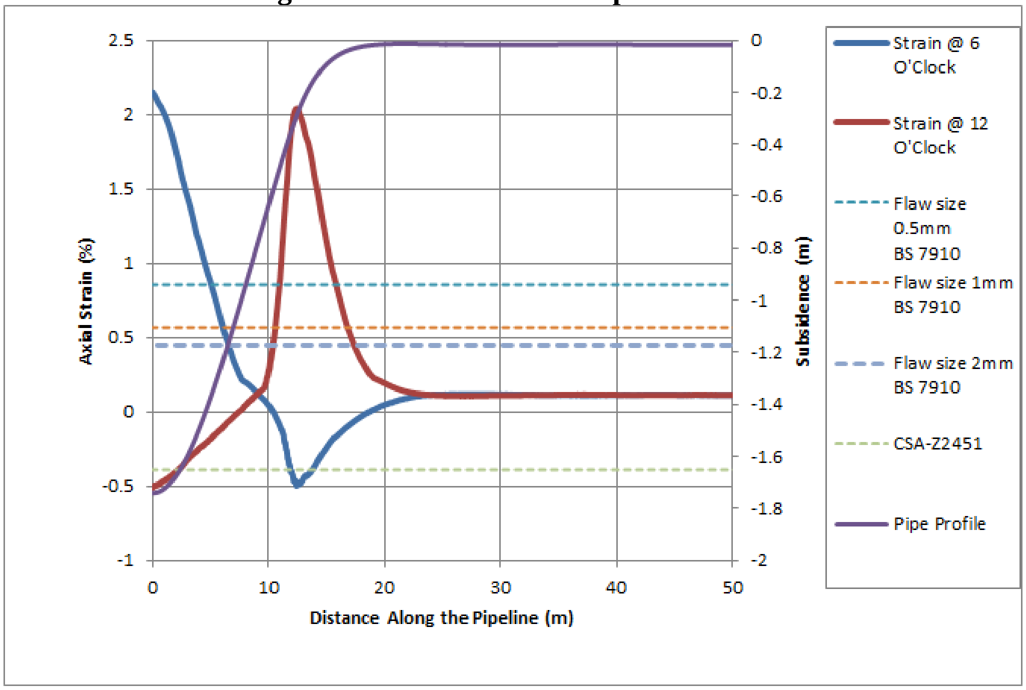

Figure 8: Predicted Pipeline Profile and Maximum Tensile Strains in the Pipe for Pit Subsidence of 2.05 m

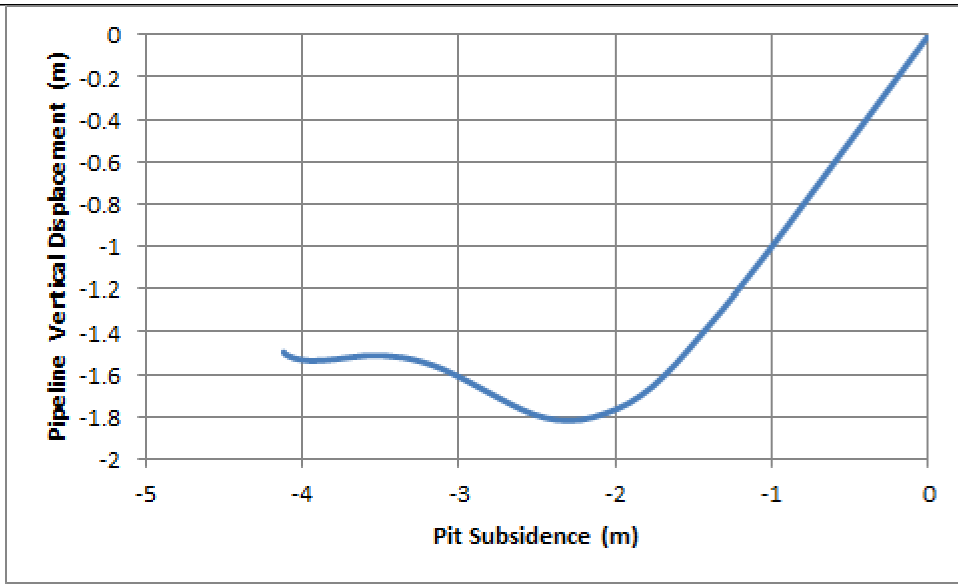

Figure 9: Peak Pipe Displacement in Relation to Pit Subsidence

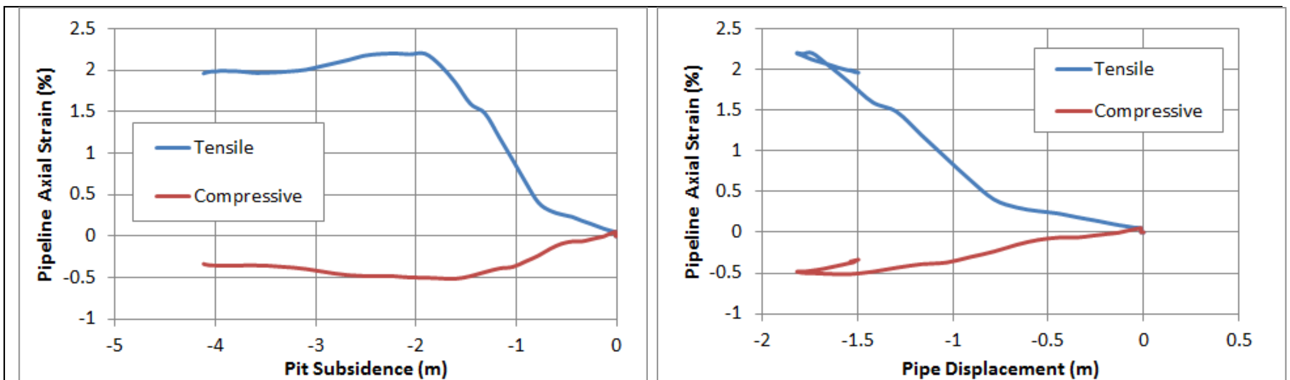

Figure 10: Maximum Tensile Strains in the Pipe in Relation to Pit Subsidence (Left) and Vertical Pipe Deflection (Right)

Task 5 –Modeling of Lateral Soil Movement

Objective: Complete a sensitivity study to define the relationship between problem parameters and the pipe strains developed in lateral soil movement events and identify trends.

Scope: The scope of this task is to develop and simulate a range of pipe soil lateral movement scenarios considering differing pipe geometries, soils, pipe materials and operating conditions to define the impact of the problem parameters (e.g., soil movement width, surcharge) on the analysis results. It is expected that the modeling process will describe pipeline response in terms of axial and bending stresses and strains (or loads), pipe deformation and potential for buckling/wrinkling. These sample modeling results will be used to develop an empirical relationship between the pipe, geotechnical and operating parameters affecting peak pipe strains.

Activities:

A sensitivity analysis is being carried out to evaluate the effects of the some key parameters, including:

- Pipe diameters and wall thickness or D/t ratio: 30”/0.5”=60, 30”/0.375=80, 30”/0.312=96, 24”/0.25”=96, 20”/0.46 =43, 20”/0.25=80
- Pipe Grade: X52 and X70
- Landslide width: Gourd movement width ranging between 5 to 100m
- Angle between the landslide and the pipeline: two loading scenario were considered lateral ground movement (perpendicular to the pipeline) and ground movement at crossing angle of 45^0. Note that the focus of the project is on lateral ground movement. The Project Team will run some cases considering two crossing angle (e.g. 45^0 and 65^0) to demonstrate the significance of at ground movement at crossing angle.

Sample Results:

- Figure 11 and Figure 12 show the peak compressive and tensile strains in the 20-inch pipeline in relation to permanent ground displacement along with the strain limits. The results in Figure are for ground movement width of 50 m and 100m at crossing angle of 45^0. The indicated that:

  a. the tensile strain related failure limits were reached for ground movement ranging from 1.4 m to 2.4 m considering flaw size of 2 mm, 1 mm and 0.5 mm, respectively;
  b. the peak tensile strains are higher than 2% for slope movement greater than 4 m; and
  c. a slope movement of 4.5 m and 5.4 m were required to reach the CSA Z662 and API RP 1111 critical compressive strain criteria, respectively.

- Figures 13 and Figure 14 show the deflection of the pipeline as results of the axial and bending load the soil movement exerts on the pipe for two analyzed cases considering slope movement width of 100 m and 50 m. The results indicated that soil movement caused axial and bending strains in the pipe. Compressive strains may results in local buckling/wrinkling of the pipe in the compressive zone. The tensile strains may result in girth weld failure in tensile strain zone.

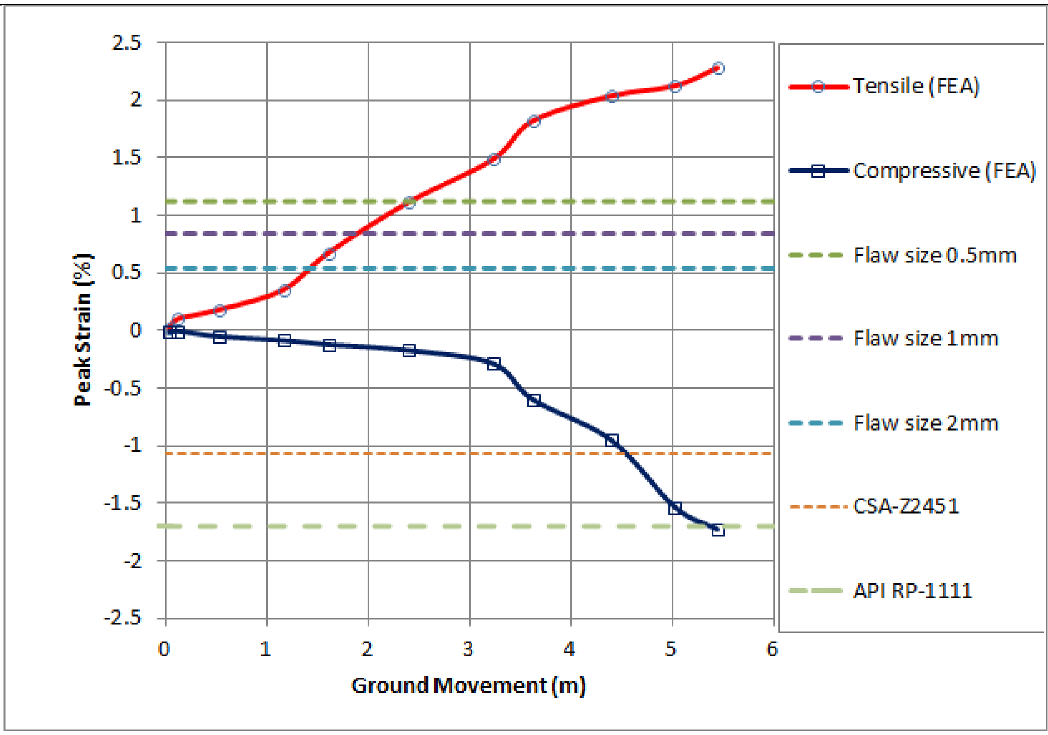

Figure 11: Maximum Axial Tensile & Compressive Strains in the Pipeline (Ground movement width of 100 m)

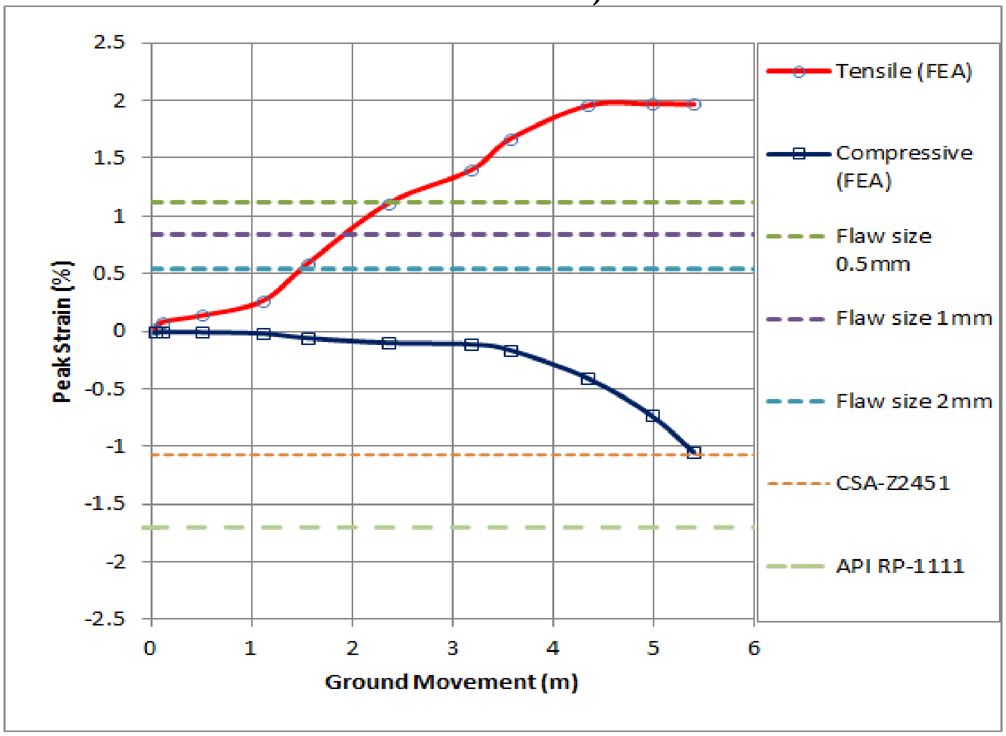

Figure 12: Maximum Axial Tensile & Compressive Strains in the Pipeline (Ground movement width of 50 m)

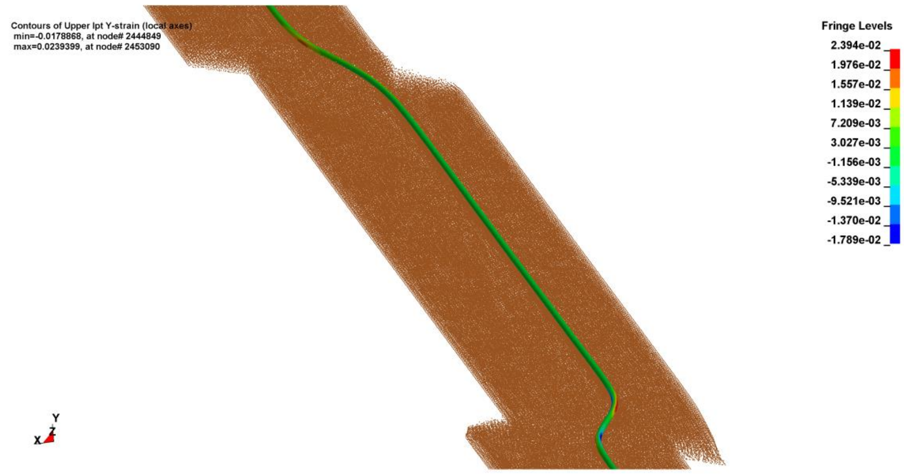

Figure 13: Pipeline Axial Strains (red tension zone, blue compression zone) for Soil Movement of 5.4 m (Failure surface width 100 m)

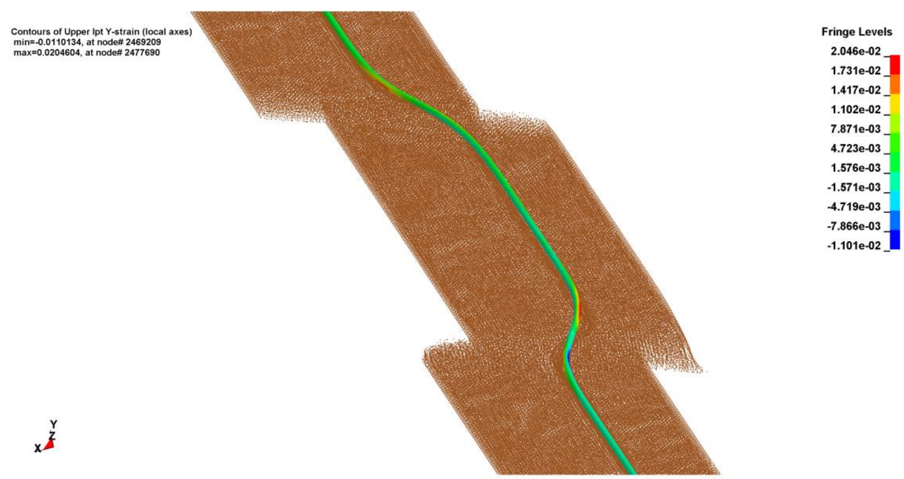

Figure 14: Pipeline Axial Strains (red tension zone, blue compression zone) for Soil Movement of 5.4 m (Failure surface width 50 m)

<u>Task 6: Project Management and Reporting</u>

The work completed in this task in the last quarter included:

- The project team prepared project status reports
- Advisory Panel review meeting and presentation

2.3 Plans for Future Activity

Over the next 30-60 days, the following activities will be conducted:

<u>Task 4: Modeling of Ground Subsidence</u>

A sensitivity analysis is being carried to define “safety envelopes” for the case where pipe is loaded by ground subsidence. Safety envelopes were defined with respect to the combination of the panel width to mining depth ratio (W/H) for various soil strengths, pipe geometry (D/t), steel grade, pipe to soil coefficient of friction, subsidence widths, Subsidence type (sag and pit subsidence).

The project team will complete and submit a report describing the geotechnical process and results in support of an information and technical direction progress meeting.

<u>Task 5 –Modeling of Lateral Soil Movement</u>

A sensitivity analysis is being carried to define “safety envelopes” for the case where pipe is loaded by lateral ground movement. Safety envelopes were defined with respect to the combination of ground displacement width for various soil strengths, pipe geometry (D/t), steel grade, pipe to soil coefficient of friction, landslide widths landslide direction to the pipeline (lateral and at crossing angle).

The project team will complete and submit a report describing the geotechnical process and results in support of an information and technical direction progress meeting.

<u>Task 7: Project Management and Reporting</u>

The project team will complete and submit the upcoming required monthly and quarterly reports.