Seventh QUARTERLY REPORT

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

SUBMITTED BY: **Team Project Manager**
Abdelfettah Fredj
BMT Fleet Technology
311 Legget Drive
Kanata, Ontario K2K 1Z8 Canada
Telephone: (613) 592-2830
E-mail: afredj@fleetech.com

TEAM TECHNICAL COORDINATOR: **Team Technical Coordinator**
Aaron Dinovitzer
BMT Fleet Technology
311 Legget Drive
Kanata, Ontario K2K 1Z8 Canada
Telephone: (613) 592-2830
E-mail: adinovitzer@fleetech.com

TEAM PARTICIPANTS: BMT Fleet Technology Limited
A Fredj, A Dinovitzer, A Hassannejadasl

SUBMITTED TO: U. S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration
Mr. Warren D. Osterberg
Agreement Officer
warren.osterberg@dot.gov

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1.0 Funds and Work Completed During this Quarterly Period

Figure 1: Federal Funds Expended On Project and Task Completion Forecast

A progress review meeting will be scheduled in November 2015 to discuss the results.

2.0 Technical Status

The project status in terms of work completion is discussed in the sections that follow.

2.1 Task 1: - Project Kickoff

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

2.2 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.

2.3 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.

Peer Review and the Analysis Results: In order to be able to react and confirm the project scope of work, a peer review meeting was held to discuss the results and observations available.

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

The presentation documents were posted to the project website.

2.4 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”/0.218”=110, 24”/0.25”=96, 24”/0.312”= 77
20”/0.218 =92, 20”/0.25=80, 20”/0.312=64,
16”/0.25=64, 20”/0.312=51, 16/0.218= 73

- Pipe Grade: X52 and X70
- Subsidence Widths: Subcritical, critical and supercritical
- Subsidence: Pit Subsidence and Sag subsidence

2.4.1 Sample Results - Comparison with Strain Criteria and Safety Envelopes

The objective was to develop a simple method to define the effects of operational and geotechnical loads on liquid and gas pipeline systems to support decision making regarding threat severity or repair scheduling. This tool incorporated in strain based design and assessment to facilitate the consideration of complex loading scenarios inducing significant flexural loads, including pipeline subsidence or lowering.

The results were interpolated, to produce Safety envelopes with respect to the combination of the panel width to mining depth ratio (W/H). Failure “not safe pipe” was presumed to occur if the tensile strain at any location exceeded strain limits defined from BS 7910, CSA-Z662 and PRCI 2004.

The strain demand determined from the analysis was compared with the calculated strain limits defined from BS7910 guidance.

The results were interpolated, to produce Safety with respect to the combination of the panel width to mining depth ratio (W/H) where the pipe was safe and not safe. Failure “not safe pipe” was presumed to occur if the tensile strain at any location exceeded strain limits defined from BS 7910, CSA-Z662 and PRCI 2004.

Figure 2 through Figure 4 show a set of pipe safety envelopes for the 16-inch, 24-inch and 30-inch for BS7910 tensile strain limits, considering a flaw size of 0.5mm, 1mm and 2mm. The results show the importance of mining depth ratio (W/H).

The results are very sensitive to the assumption made regarding the key analysis parameters. A further 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 and pipe to soil coefficient of friction.

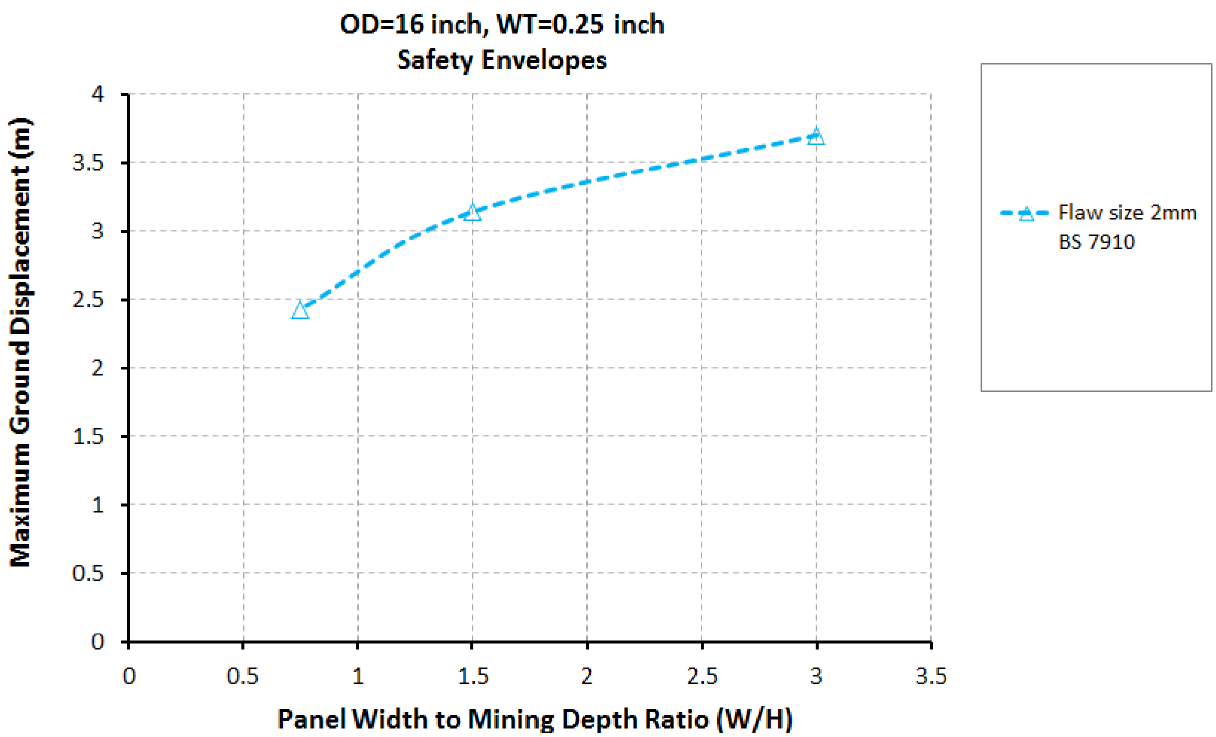

Figure 2: Safety Envelope: 16-inch – Tensile Strain Limit

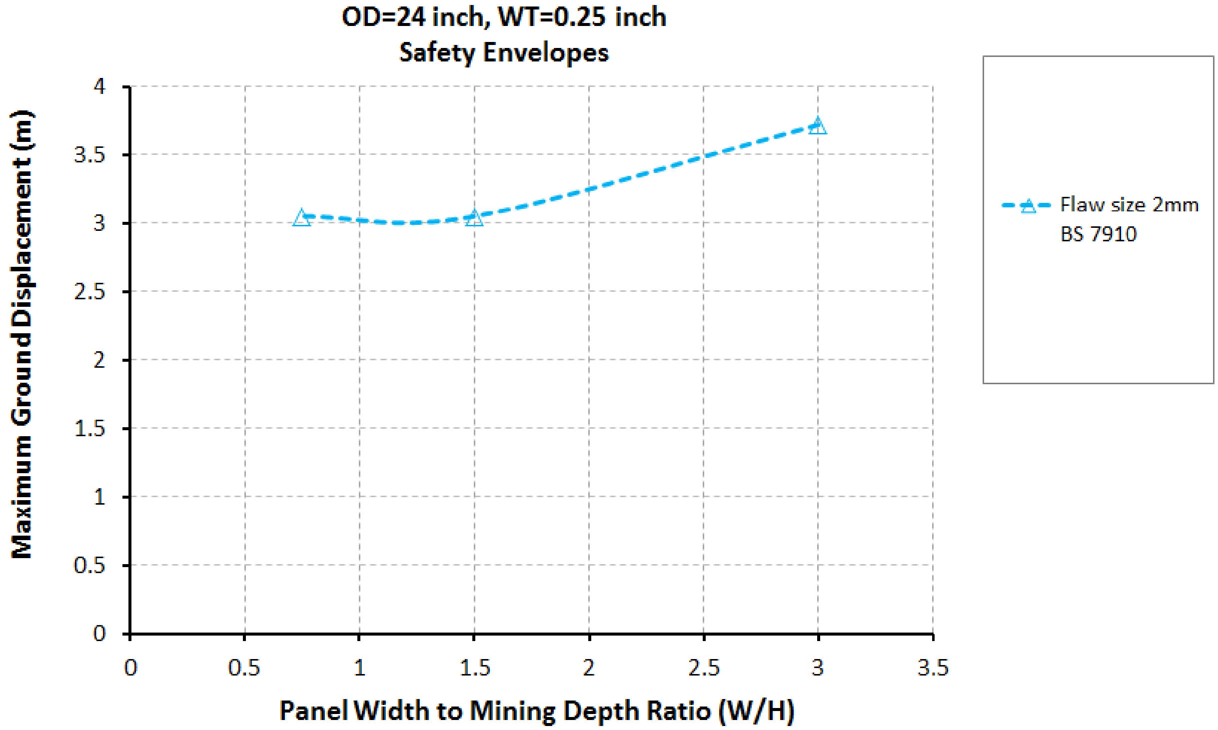

Figure 3: Safety Envelope: 24-inch – Tensile Strain Limit

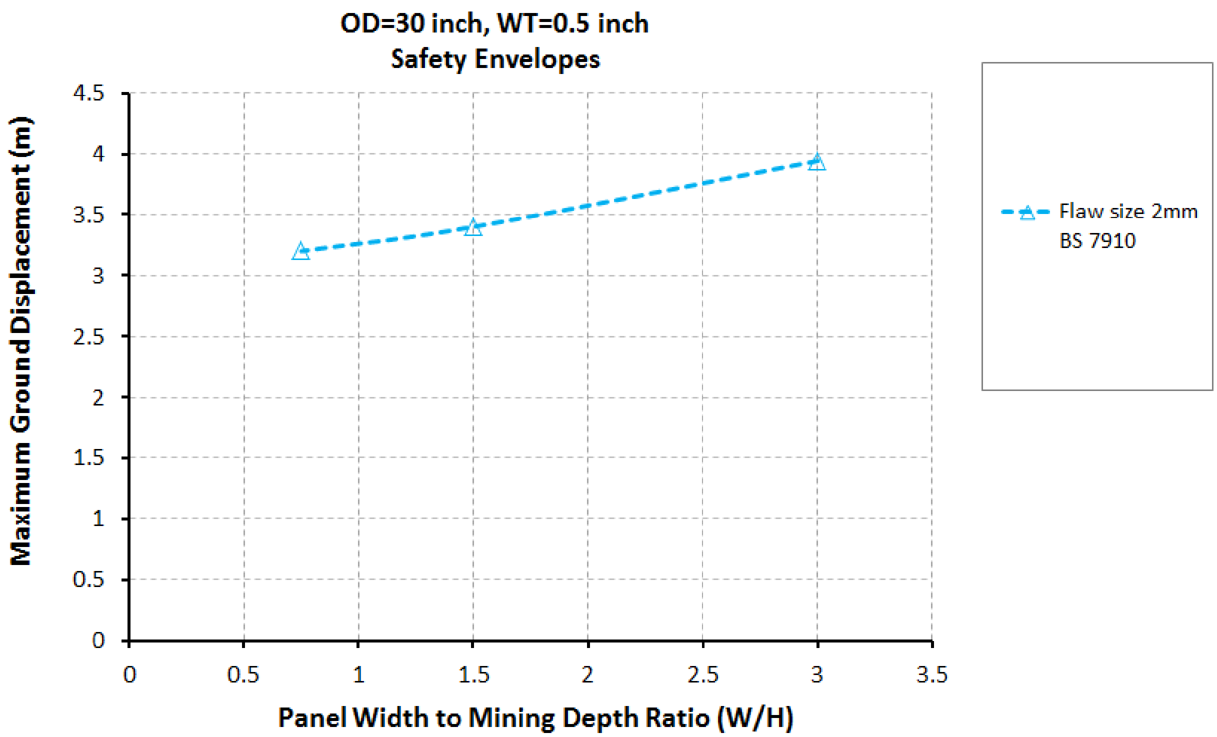

Figure 4: Safety Envelope: 30-inch – Tensile Strain Limit

2.4.2 Sample Results – Pipe Displacement and Strain Response

Figures 5 through 8 provide information on the pipe displacement and strains resulting from the subsidence hazard.

Figure 5 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 6 through Figure 8 plot the surface subsidence profile, pipeline profile and pipeline axial strains distribution at different clock position (6 and 12 o'clock) along the length of the pipeline. The results presented in these Figures are for 24-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).

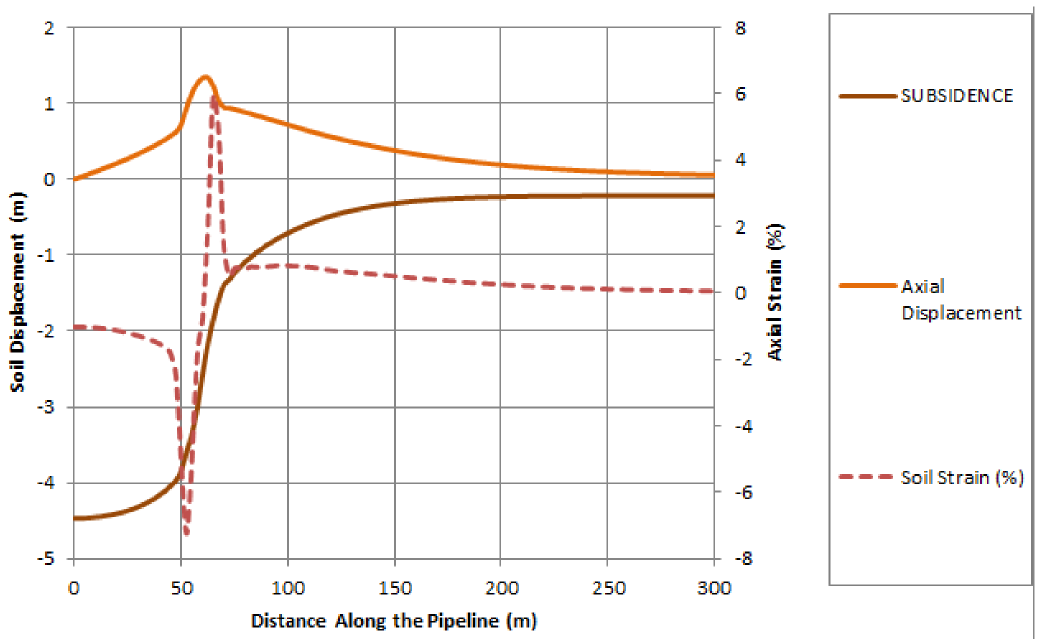

Figure 5: Predicted Subsidence Profile along the Pipeline and Maximum Axial soil displacement and Tensile Strains in the Soil

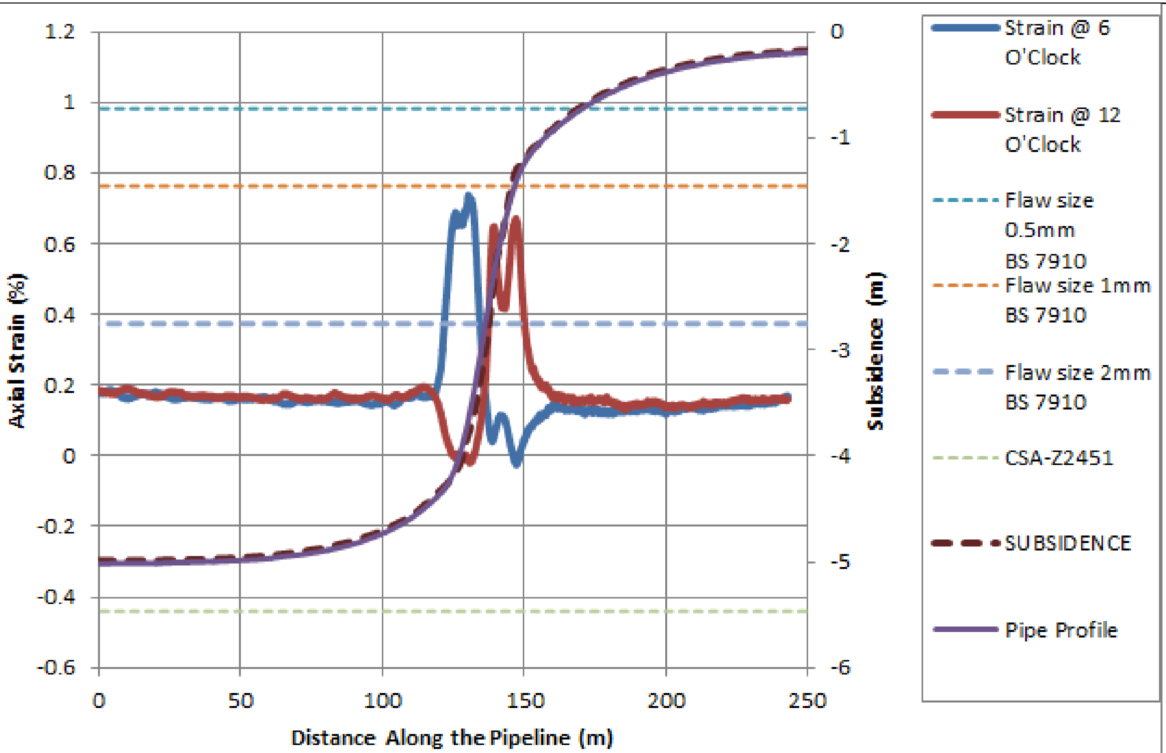

Figure 6: Predicted Pipeline, Subsidence Profiles and Maximum Tensile Strains in the Pipe in for Mining Depth Ratio (W/H=3)

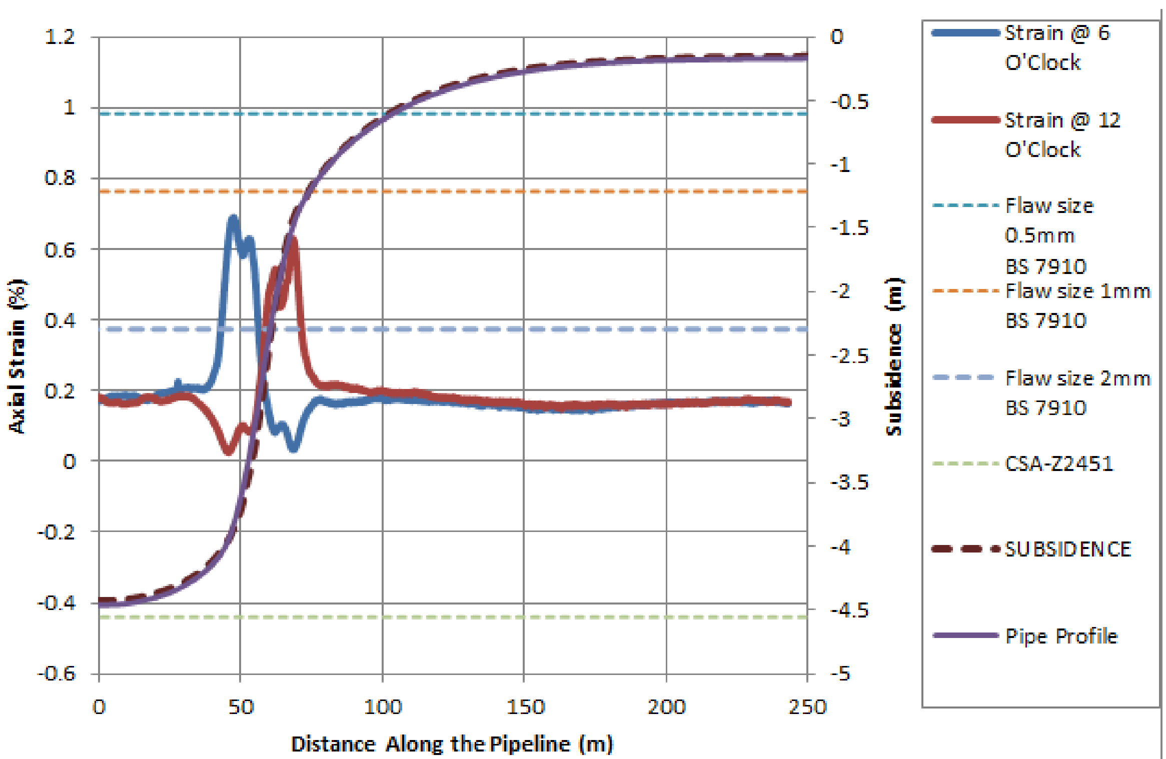

Figure 7: Predicted Pipeline, Subsidence Profiles and Maximum Tensile Strains in the Pipe in for Mining Depth Ratio (W/H=1.5)

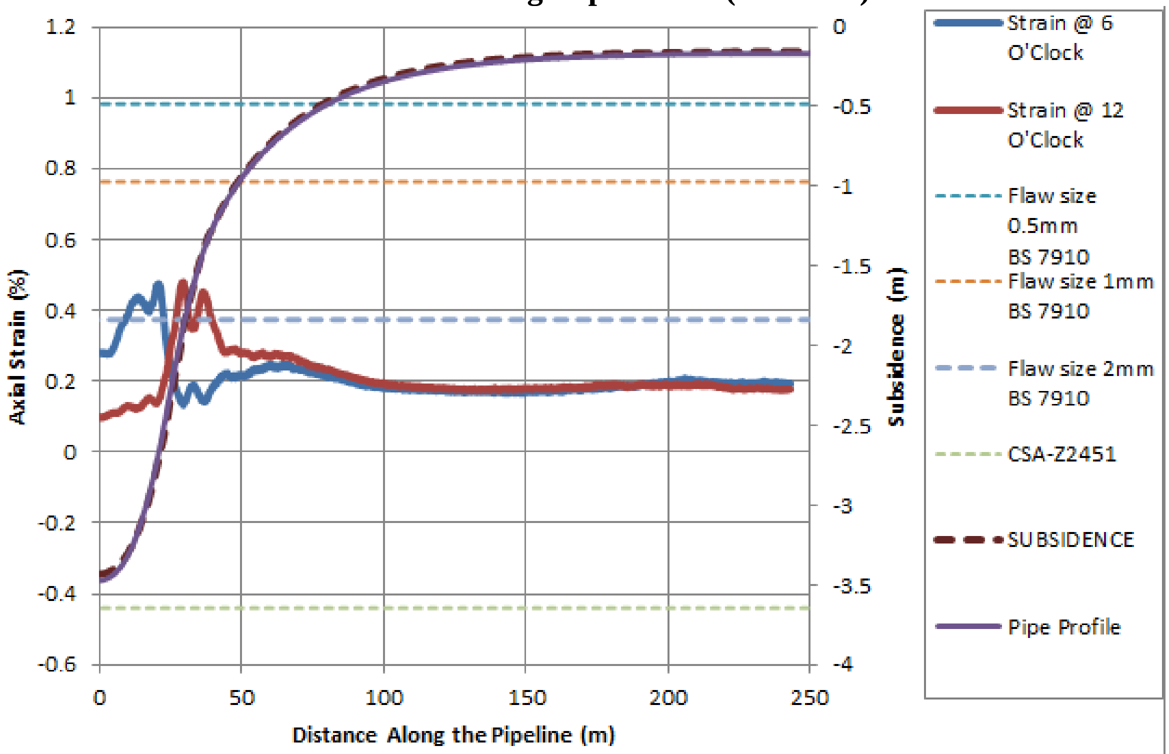

Figure 8: Predicted Pipeline, Subsidence Profiles and Maximum Tensile Strains in the Pipe in for Mining Depth Ratio (W/H=0.75

2.5 Task 5 –Modeling of Lateral Soil Movement

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

<u>Scope</u>:
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.

<u>Activities</u>:
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”/0.218”=110, 24”/0.25”=96, 24”/0.312”= 77
20”/0.218 =92, 20”/0.25=80, 20”/0.312=64,
16”/0.25=64, 20”/0.312=51, 16/0.218= 73

- 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.

2.5.1 Sample Results - Comparison with Strain Criteria and Safety Envelopes

The objective was to develop a simple method to define the effects of operational and geotechnical loads on liquid and gas pipeline systems to support decision making regarding threat severity or repair scheduling. This tool incorporated in strain based design and assessment to facilitate the consideration of complex loading scenarios inducing significant flexural loads, including pipeline subsidence or lowering, and ground movements inducing lateral pipeline movements.

The results were interpolated, to produce an envelope defining the combinations of ground displacement and width where the pipe was safe and not safe. Failure “not safe pipe” was presumed to occur if the tensile strain at any location exceeded strain limits defined from BS 7910, CSA-Z662 and PRCI 2004.

Tensile Strain Criteria and Safety Envelopes

The strain demand determined from the analysis was compared with the calculated strain limits defined from BS7910 guidance.

Figures 9 and 10 show a sample results of axial tensile and compressive strains in the 24-inch pipe as a function of the centerline of lateral soil displacement for various lateral soil widths [5–50m].

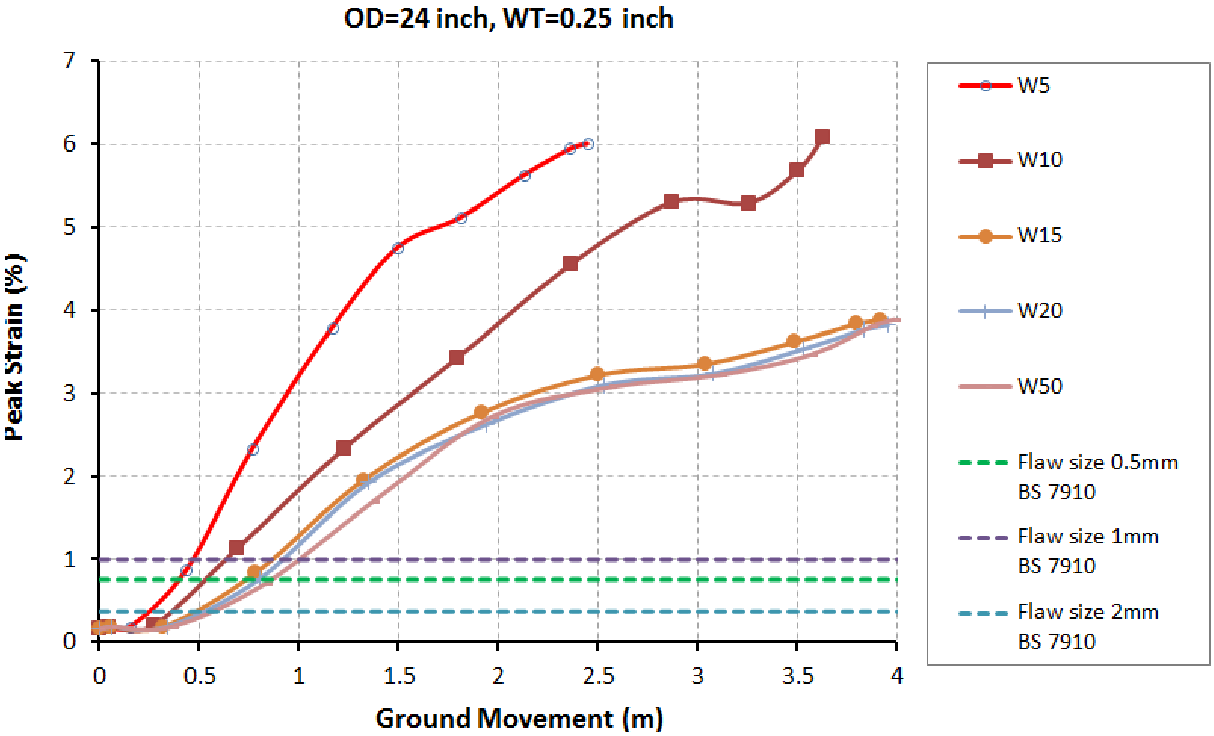

Figure 9: Maximum Tensile Strains in the 24-inch Pipe vs. Ground Movement Width [5-50m]

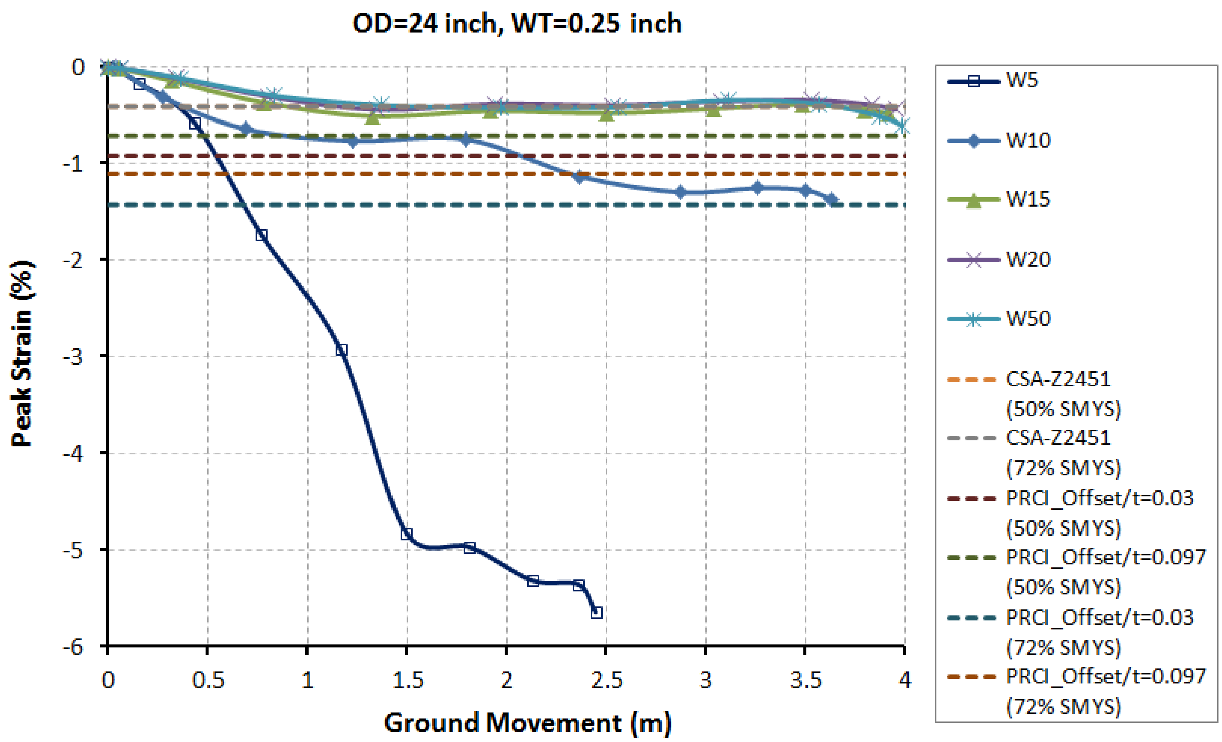

Figure 10: Maximum Compressive Strains in the 24-inch Pipe vs. Ground Movement Width [5-50m]

The results were interpolated, to produce an envelope defining the combinations of ground displacement and width where the pipe was safe and not safe. Failure “not safe pipe” was presumed to occur if the tensile strain at any location exceeded strain limits defined from BS 7910, CSA-Z662 and PRCI 2004.

Figure 11 trough Figure 13 show a set of pipe safety envelopes for the 16-inch, 24-inch and 30-inch for BS7910 tensile strain limits, considering a flaw size of 0.5mm, 1mm and 2mm. The results show the importance of ground soil movement width. It shows that the critical soil movement width that maximizes pipe bending moments and strains are about 5 m to 10 m for the 16-inch, 24-inch and 30-inch pipes.

The results are very sensitive to the assumption made regarding the key analysis parameters. A further 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 and pipe to soil coefficient of friction.

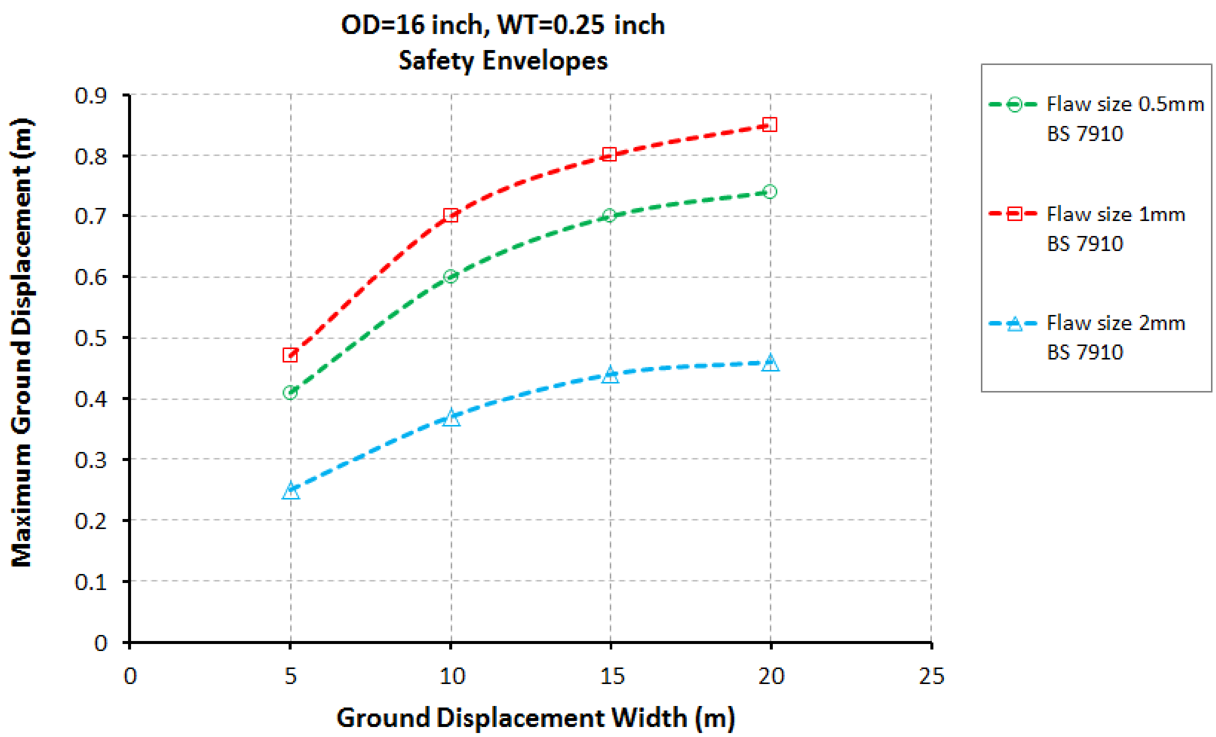

Figure 11: Safety Envelope: 16-inch – Tensile Strain Limit

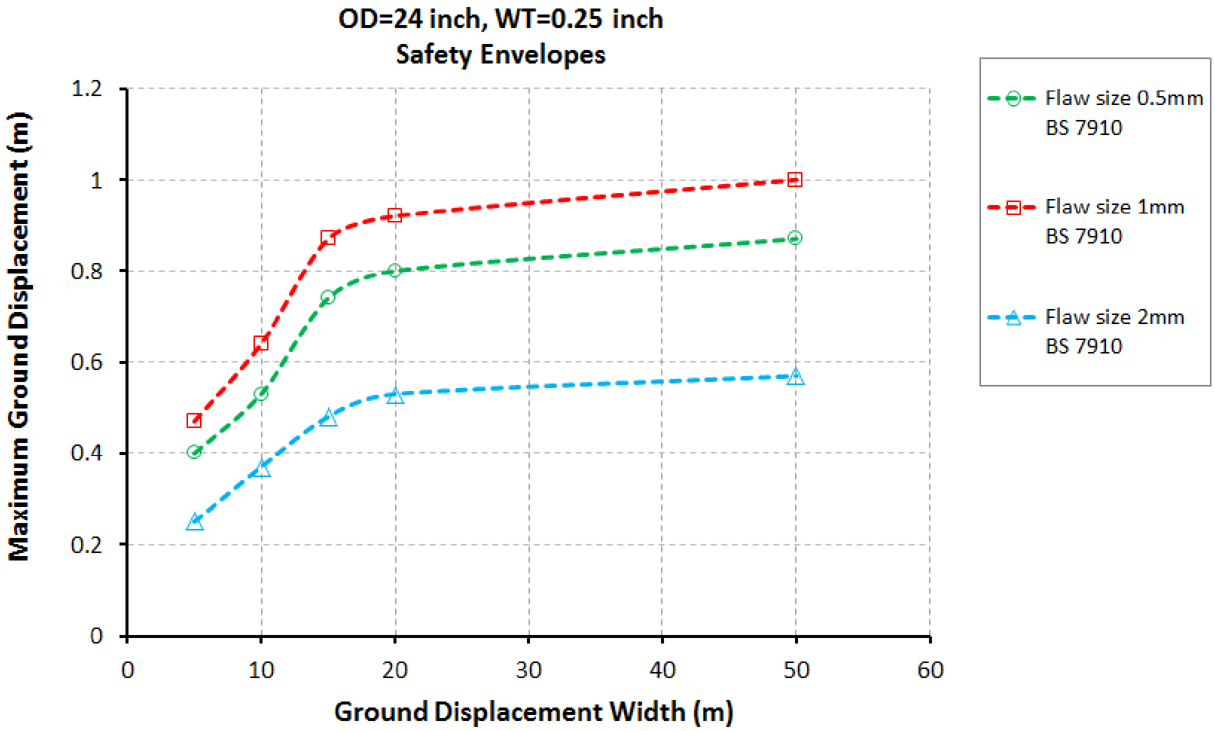

Figure 12: Safety Envelope: 24-inch – Tensile Strain Limit

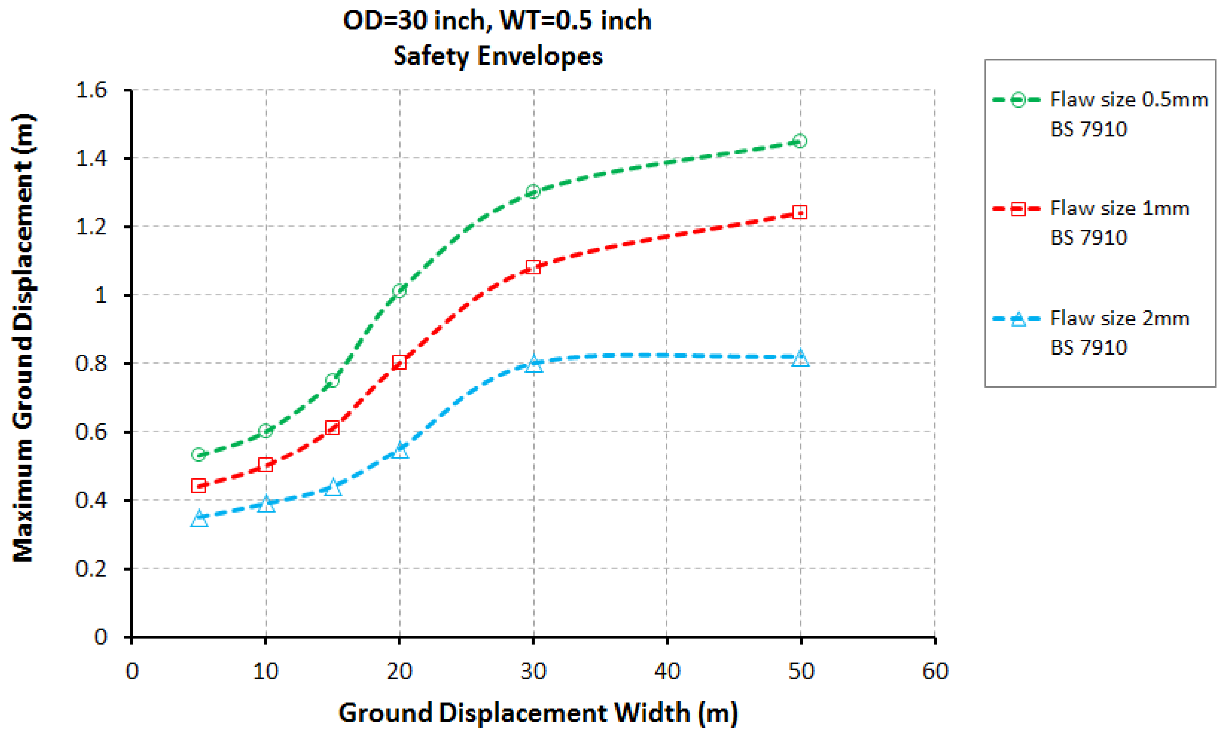

Figure 13: Safety Envelope: 30-inch – Tensile Strain Limit

2.5.2 Sample Results – Pipe Strain

Figure 14 through Figure 17 show the true axial strain at 3'oclock and 9 o'clock position along the pipeline in the 24-inch pipeline , with D/t ratio of 96 and material grade X52. The results in Figure are for ground movement width of 5 m, 10 and 15 m considering a soil movement of 1.9 m.

The analysis has demonstrated that pipeline parameters and operating loading have a significant effect on the pipeline response and integrity. For a given pipe geometry and operating conditions, there is a critical lateral soil movement width that maximizes pipe bending moments and strains. The critical soil movement width is about 5 m for the 24 inch pipeline. Figure 17 shows the pipe deformation considering ground movement width of 5m; the pipe exceeds the compressive strain limit and buckle/wrinkle. A sensitivity analysis is being carried and more details will be provided in the next progress report.

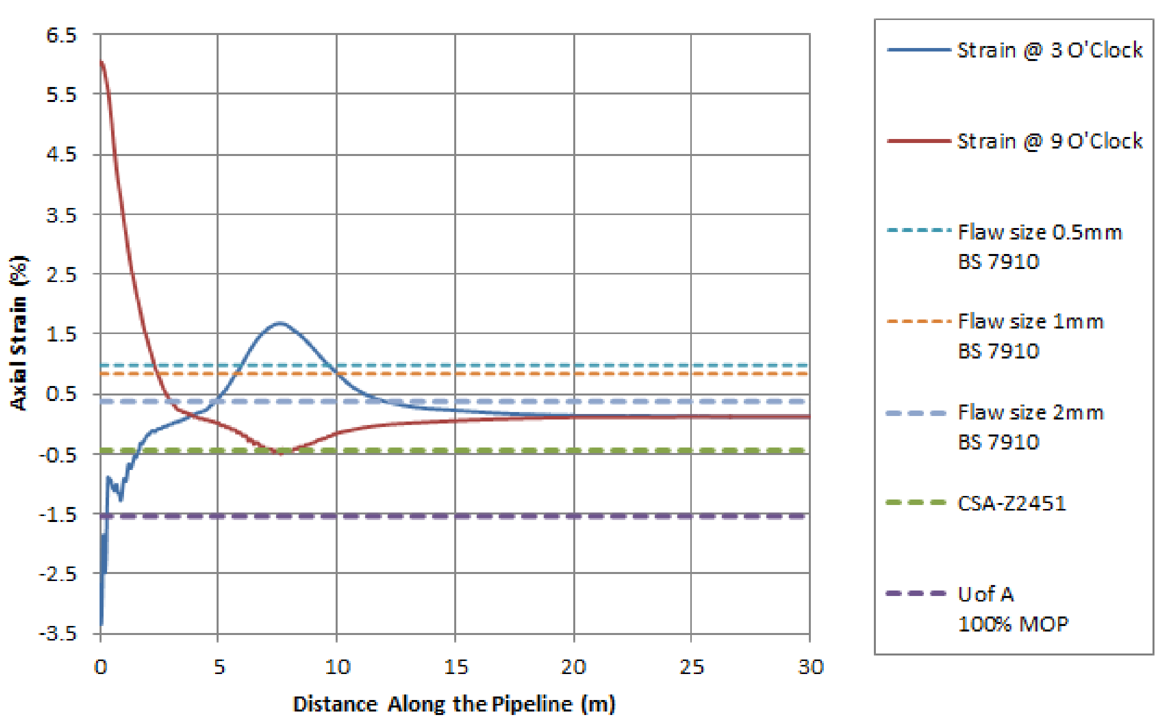

Figure 14: Maximum Axial Tensile & Compressive Strains in the Pipeline (Ground movement width of 5 m) Considering Ground Displacement of 2 m

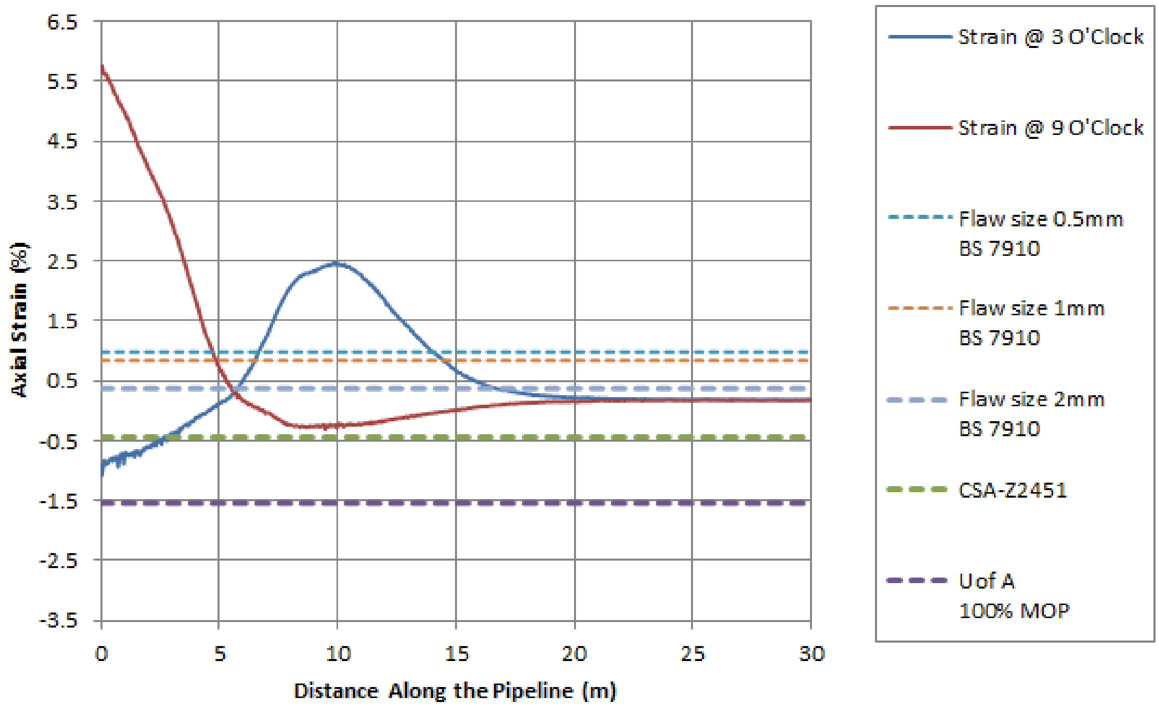

Figure 15: Maximum Axial Tensile & Compressive Strains in the Pipeline (Ground movement width of 10 m) Considering Ground Displacement of 2 m

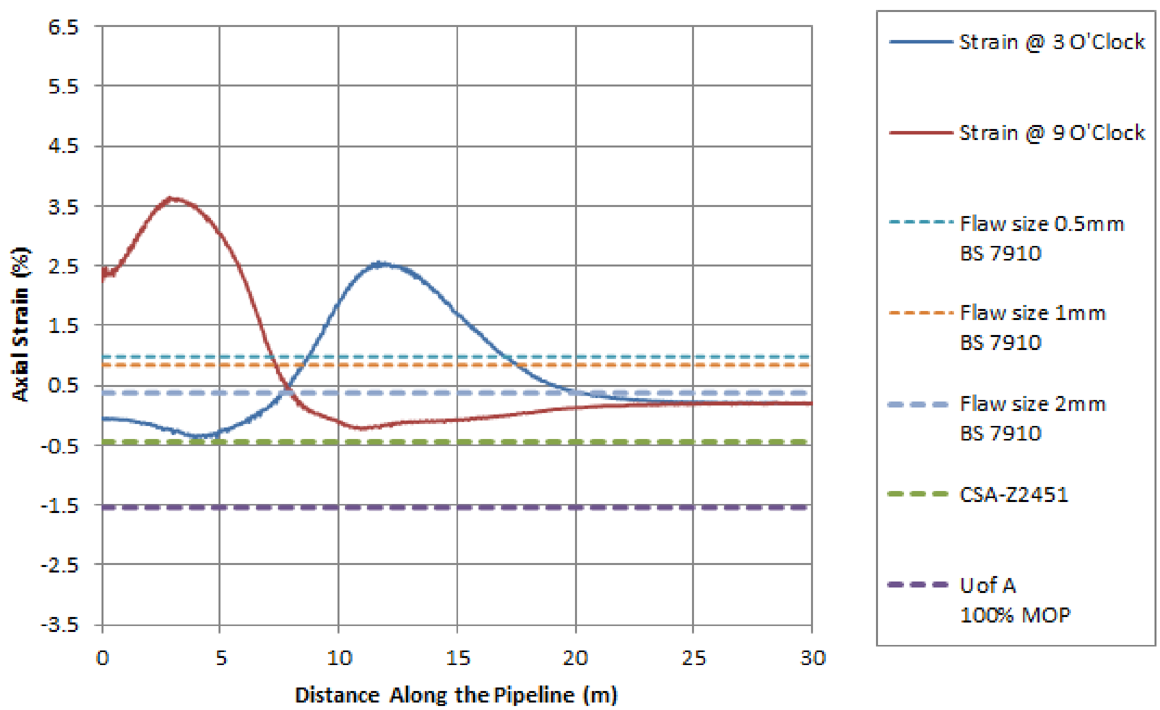

Figure 16: Maximum Axial Tensile & Compressive Strains in the Pipeline (Ground movement width of 15 m) Considering Ground Displacement of 2 m

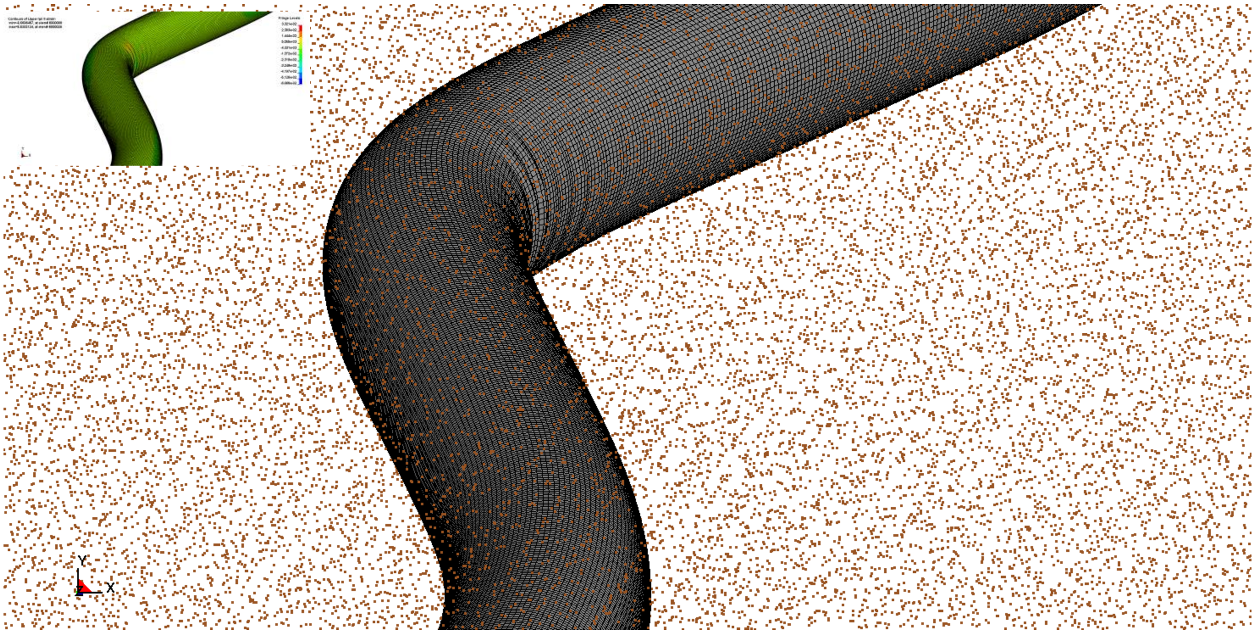

Figure 17: Pipeline Deformation (Ground movement width of 15 m) Considering Ground Displacement of 2 m

2.6 Task 6: Project Management and Reporting

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

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

3.0 Plans for Future Activity

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

Task 4: Modeling of Ground Subsidence

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.

Task 5 –Modeling of Lateral Soil Movement

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.

4.0 Business Status