Second 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 and R Gailing

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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2.0 Technical Status

2.1 Technical Progress

Task 1: - Project Kickoff

- The project team, consisting of BMT Fleet Technology, held the required Kick Off meeting via teleconference and webinar on March 5, 2014 with DOT/PHMSA's Julie Halliday.
- 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 is being prepared for submission in the next couple of days.

Task 3: Model Development and Demonstration

3.1 Modeling of Subsidence Hazard

The project team has progressed the development of a numerical model to simulate subsidence hazard events in previous months. The following provides an over view of the work to date:

- The project team completed the preparation of a 3D continuum model to predict surface subsidence due to coal-seam mining. The development was conducted in two steps. In the first step, the soil model considered only the prediction of ground subsidence due to coal-seam mining without considering the effects on pipelines. In the second step, the model considered both the prediction of the ground subsidence and the effects on the pipeline.
- Three subsidence simulations were completed to predict the pipeline response to surface subsidence due to coal-seam mining and illustrate the impact of the width of subsidence area on the analysis results.
- The analyses were completed for a 30-inch pipeline with 7.92 mm wall thickness, considering the subsidence resulting from a longwall mine face length of 300 m, seam depth of 100m, extraction height of 5m, and three different extraction widths including:
  - Case1: Sub-critical panel extraction width– of W=75 m that has a W/H ratio of 0.75
  - Case2: Critical panel extraction width of 150 m with a W/H ratio of 1.5
  - Case3: Super-critical panel extraction width of 300 m with W/H ratio of 3.

- Subsidence Profiles: The subsidence profiles predicted by finite element analyses were compared with the best known empirical methods, NCB method and Appalachian methods. NCB Method and Appalachian method. The results presented in the previous quarterly report indicated that while there is a difference in the subsidence profile from one empirical method to the other, the FEA model prediction is closer to the NCB method. The FE model results predicted a less abrupt curvature than the NCB method for these cases. The results are sensitive to input parameters including soil properties which are not explicitly considered in the NBC and Appalachian empirical models.

- Pipeline Response to Surface Subsidence: The analyses results including pipeline profile and pipeline axial strains distribution at different clock positions (3, 6 and 12 o'clock) along the length of the pipeline were presented in the previous quarterly report.
- Progress and Next Steps: During this quarter, the project team refined the 3D continuum subsidence model to reduce the simulation time. Sensitivity analyses were carried out considering a 40 inch pipe to evaluate the effect of pipe diameter over wall thickness ratio (D/t). The analyses results will be presented in the next progress report.

3.2 Modeling of Landslide Hazard

The project team has progressed the development of a numerical model to simulate lateral soil movement events. The following provides an over view of the work to date:

- The project team completed the development of a 3D continuum model using smooth particles hydrodynamics (SPH) method to assess the pipeline response subjected to lateral soil movement.
- The model is a coupled 3D continuum model that can consider the effects of layered soils, trench geometries, operating conditions, and pipe materials stress-strain behavior including differences in tensile and compressive material behaviors.
- Three lateral soil movement hazard cases were analyzed to predict the pipeline response to lateral ground movement and illustrate the impact of the width of the lateral soil movement on the analysis results.
- The analyses were completed for a 30-inch pipeline with a 7.92 mm wall thickness, considering three lateral soil movement widths of 10, 20 and 40 m.
- Analysis Results: The analyses results were presented in the previous quarterly report. 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. In this quarter, a sensitivity analyses were carried out to evaluate effects of pipe diameter to wall thickness ratio and (D/t) and lateral soil movement widths.
  - Analyses were completed for a the 30-inch pipeline with a 7.92 mm wall thickness, considering a total of seven lateral soil movement widths, W (i.e. 5,10, 15, 20, 30, 40, 50 m)
  - Analyses were completed for a 40-inch pipeline with a 9.52 mm wall thickness, considering seven six lateral soil movement widths, W (i.e. 5, 10, 15, 20, 30, 40, 50 m)
  - The following Figures illustrate the SPH Finite element model and snapshots of the finite element model output.
    - Figure 2 illustrate the SPH Finite element model including the pipe in an elevation view. Figure 3 illustrates the model in plan view demonstrating the lateral movement of the soil where the pipeline trench backfill is the pink material.
    - Figure 4 illustrates the response of pressurized pipeline subjected to ground movement (W) of 10 m. Figure 4 shows also the axial strains distribution (blue color is compressive and red is tensile strain); in this

Figure the soil above the pipe is hidden so the pipe deformation can be visualized.

- Figure 5 illustrates the response of pressurized pipeline subjected to ground movement for a movement width (W) of 20 m. Figure 5 shows also the axial strains distribution (blue color is compressive and red is tensile strain); in this Figure the soil above the pipe is hidden so the pipe deformation can be visualized.
- Figure 6 illustrates the response of pressurized pipeline subjected to ground movement for movement width (W) of 40 m. Figure 6 shows also the axial strains distribution (blue color is compressive and red is tensile strain); in this Figure the soil above the pipe is hidden so the pipe deformation can be visualized
- Figure 7 illustrates an example of ground movement profile at different levels of movements considering movement width (W) of 20 m. The soil displacements illustrated in this Figure illustrate that the soil moves uniformly up to a shear zone at the limits of the displacement zone.
- Figure 8 illustrates an example of 30-inch pipeline deformation profile at different levels of ground movement considering ground movement width of 20 m. These results compared with those in Figure 7 illustrate that the pipe does not follow the same profile since some of the soil flows around the pipe.
- Figure 9 illustrates an example of 40-inch pipeline deformation profile at different levels of ground movement considering ground movement width of 20 m. These results compared with those in Figure 7 illustrate that the pipe does not follow the same profile since some of the soil flows around the pipe.
- Figure 10 shows the true axial strain at 3'oclock and 9 o'clock position along the pipeline for 30-inch pipe considering lateral soil movement width of 10 m and soil displacement of 1.93 m
- Figure 11 shows the true axial strain at 3'oclock and 9 o'clock position along the pipeline for 40-inch pipe considering lateral soil movement width of 10 m and soil displacement of 1.93 m
- Figure 12 and Figure 13 show the axial tensile and compressive strains in the 30-inch pipe as a function of the centerline of lateral soil displacement for various lateral soil widths [5 – 50 m]. 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 10m for the 30 inch pipe.
- Figure 14 and Figure 15 show the axial tensile and compressive strains in the 40-inch pipe as a function of the centerline of lateral soil displacement for various lateral soil widths [5 – 50 m]. The results show the importance of ground soil movement width. It shows that the critical soil movement width is about 10 to 15 m for the 40-inch pipe, and that the critical width increase with soil displacement magnitude. The critical width is about 10

m for soil displacement range from 0 to 1.6 m and 15 m for higher soil displacements.

- Progress and Next Steps: 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 10 m for the 30-inch pipeline and about 10 to 15 m for the 40-inch pipe. A sensitivity analysis is being carried to evaluate the effect of soil properties and more details will be provided in the next progress report.

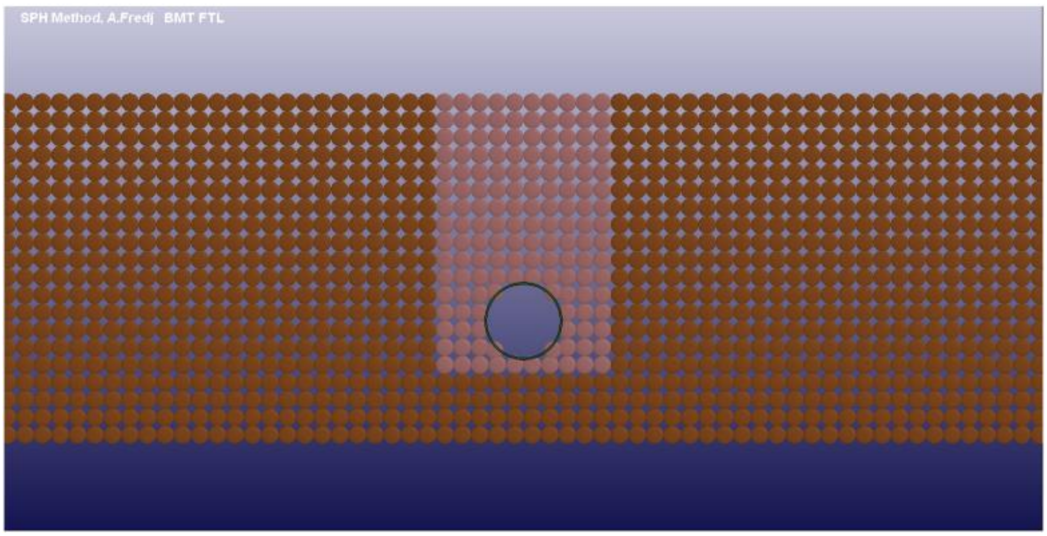

Figure 2: Illustration of the SPH FE Model Including the Pipe-Side Wiew

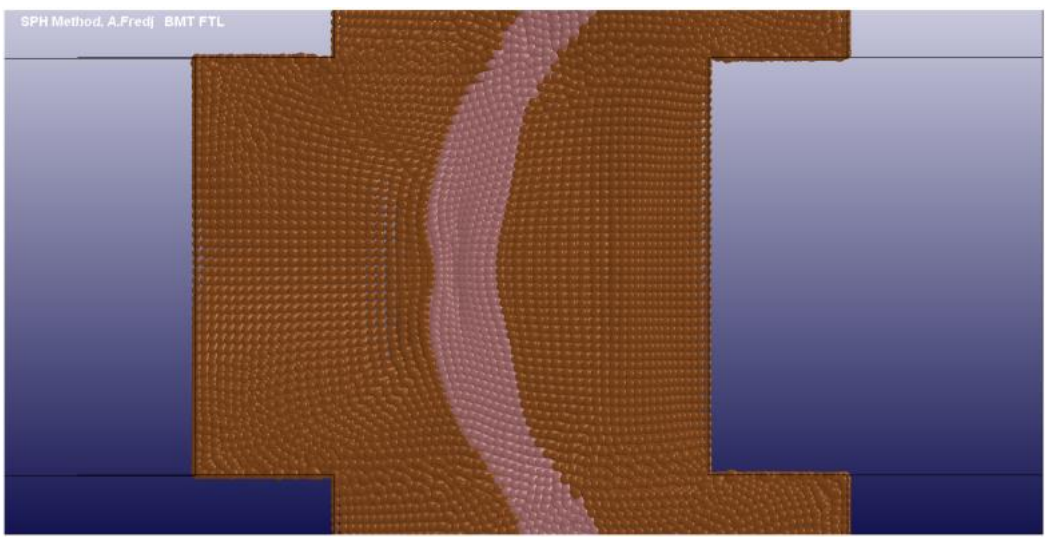

Figure 3: Illustration of the SPH FE Model Simulation

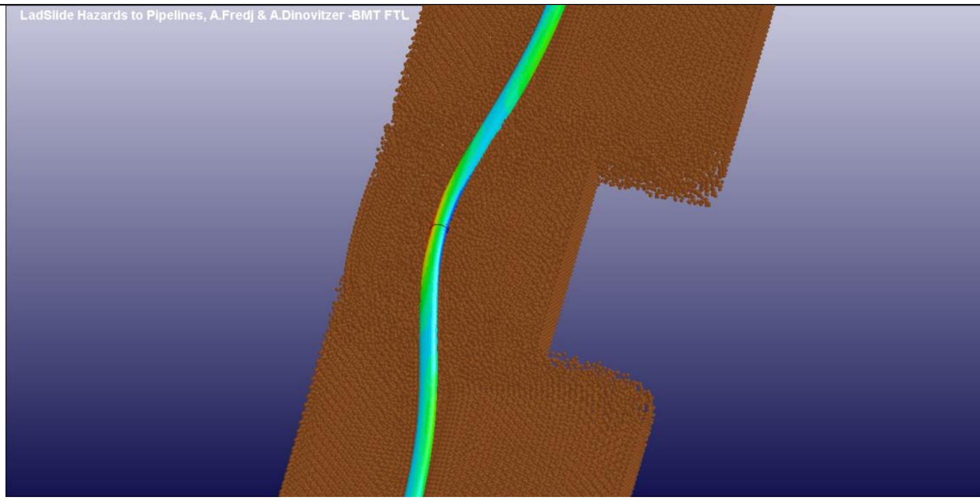

Figure 4: Pipe Deformation & Axial Strain (blue compressive and red is Tensile) for Soil Movement of 4.9 m & Width= 10 m

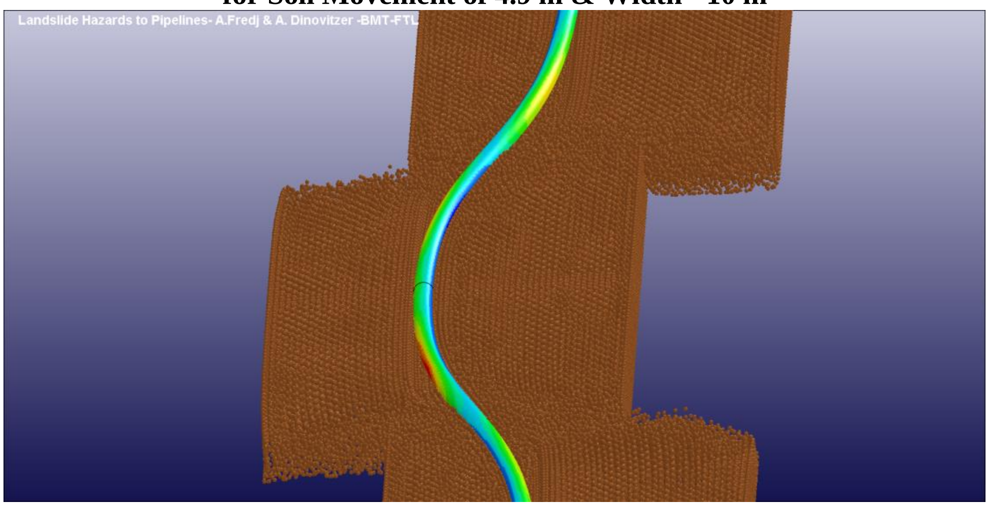

Figure 5: Pipe Deformation & Axial Strain (blue compressive and red is Tensile) for Soil Movement of 4.9 m & Width= 20 m

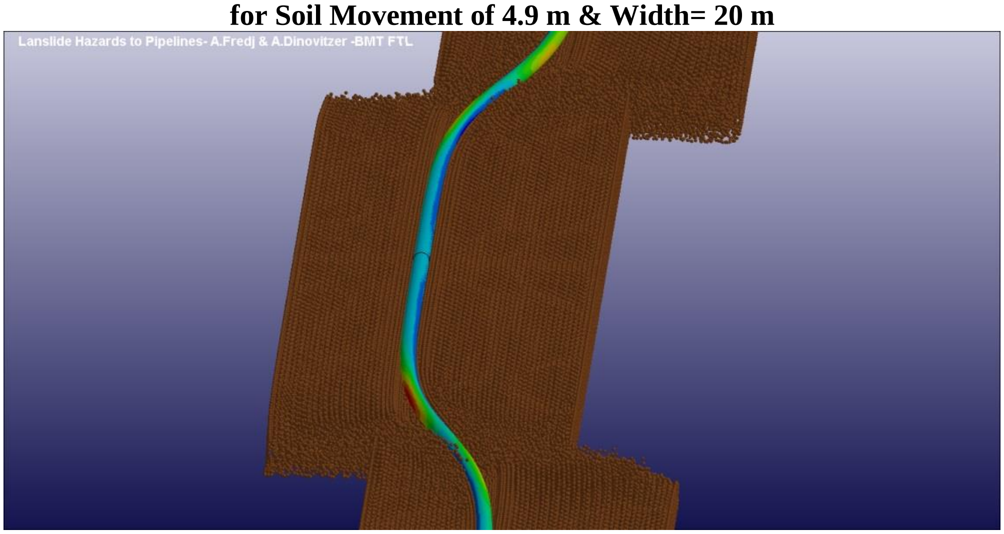

Figure 6: Pipe Deformation & Axial Strain (blue compressive and red is Tensile) for Soil Movement of 4.9 m & Width= 40 m

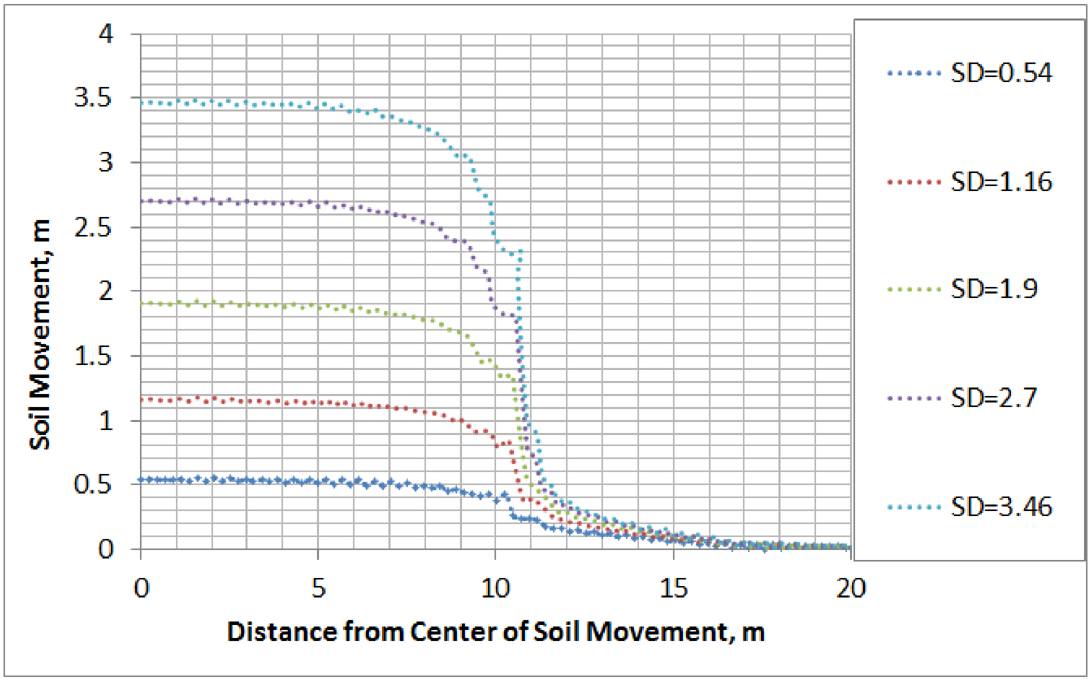

Figure 7: Ground Movement Profiles at Different Levels of Soil Movement for Displacement Width (W) = 20 m

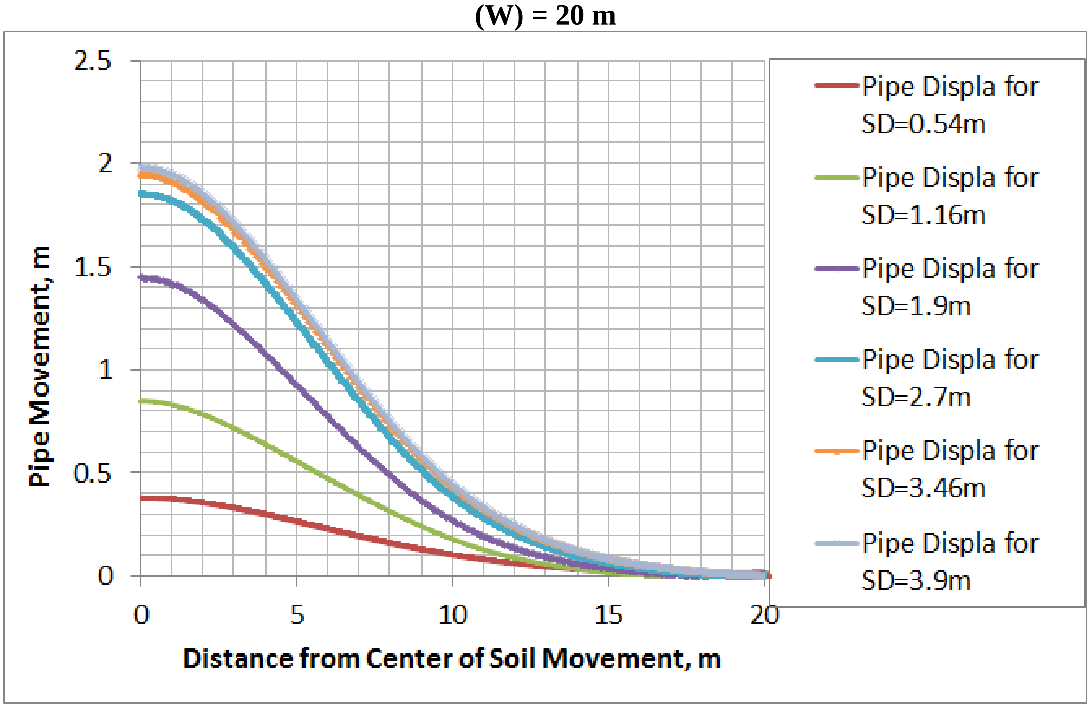

Figure 8: Pipe Movement Profiles of the 30-inch Pipe at Different Levels of Soil Movement for Displacement Width (W)=20 m

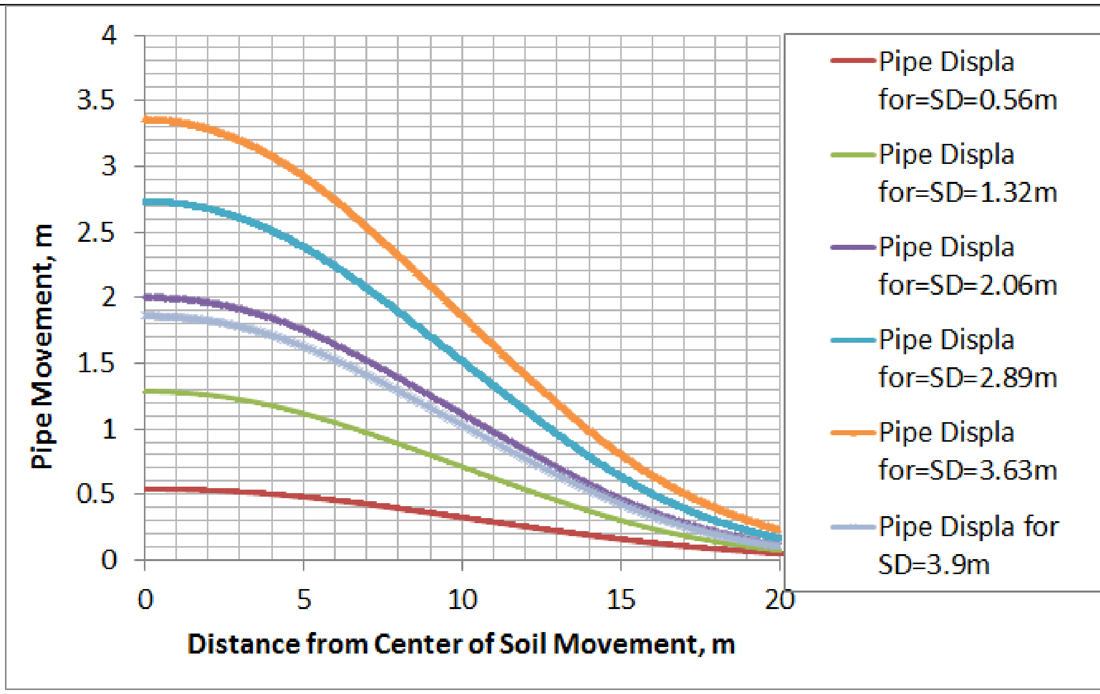

Figure 9: Pipe Movement Profiles of the 40-inch Pipe at Different Levels of Soil Movement for Displacement Width (W) =20 m

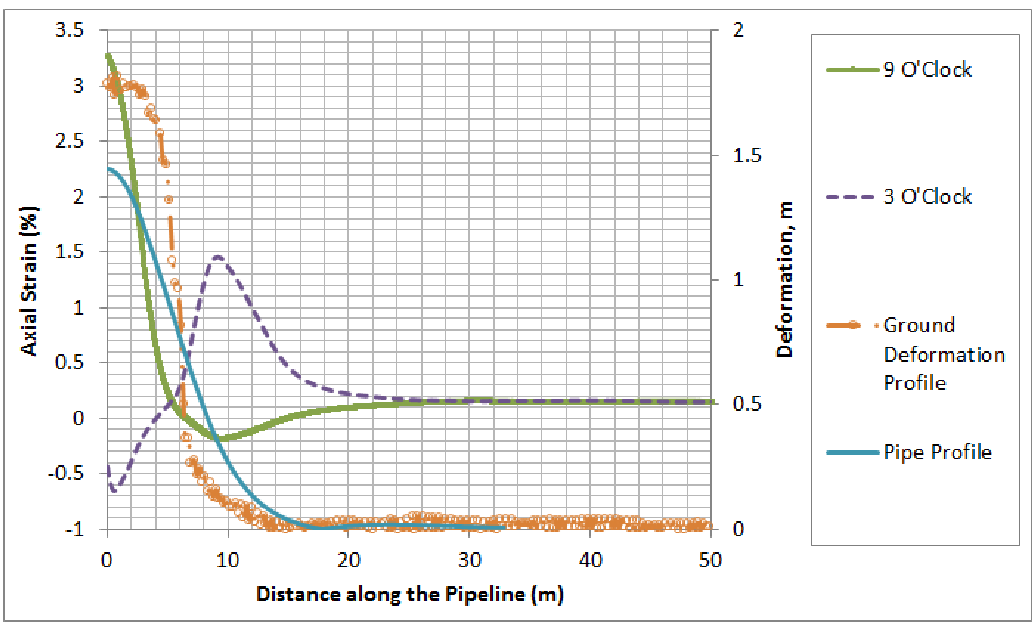

Figure 10: Calculated Axial Strains in 30-inch Pipe & Pipe and Ground Movement Profiles for Displacement Width (W) =10 m considering Soil Movement of 1.93 m

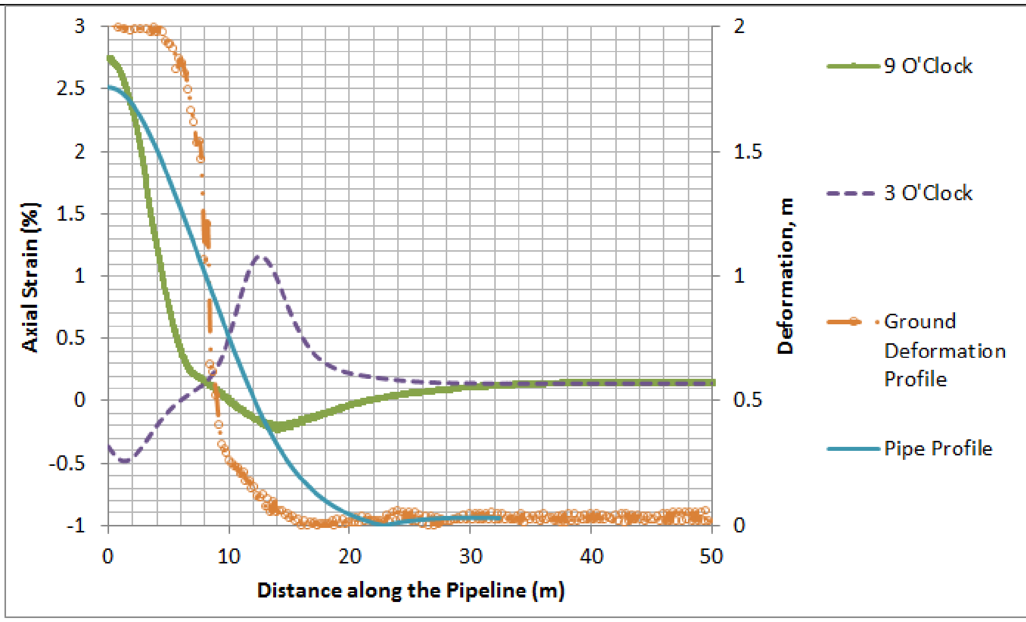

Figure 11: Calculated Axial Strains in 40 inch Pipe & Pipe and Ground Movement Profiles for Displacement Width (W)=15 m considering Soil Movement of 2 m

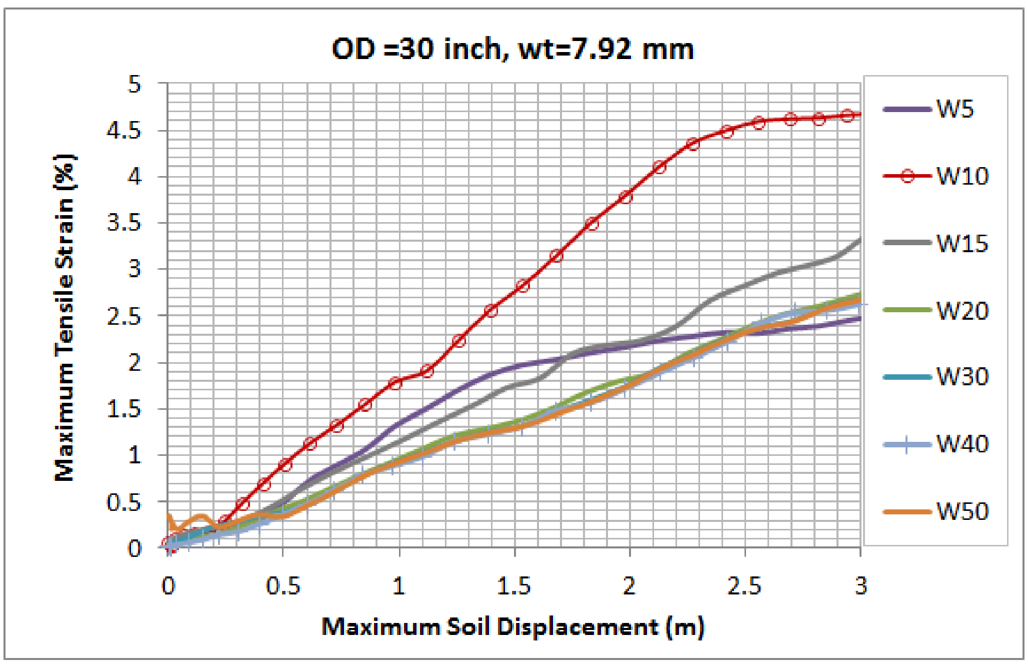

Figure 12: Calculated Tensile Strains in 30-inch Pipe Due to Lateral Soil Displacement for Lateral Ground Displacement Widths [0 – 50 m]

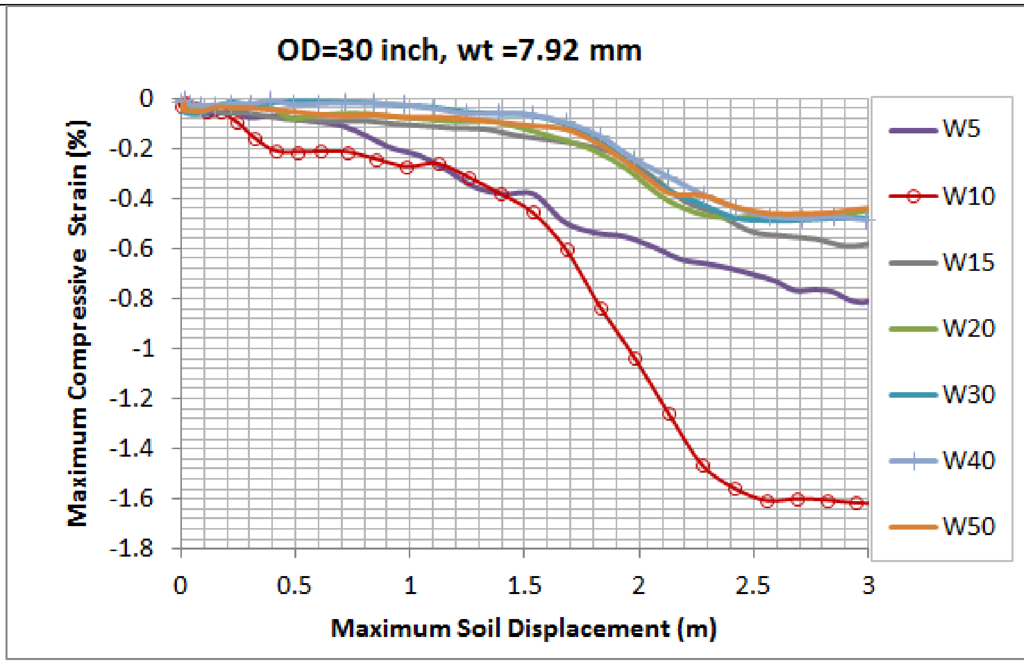

Figure 13: Calculated Compressive Strains in 30-inch Pipe Due to Lateral Soil Displacement for Lateral Ground Displacement Widths [0 – 50 m]

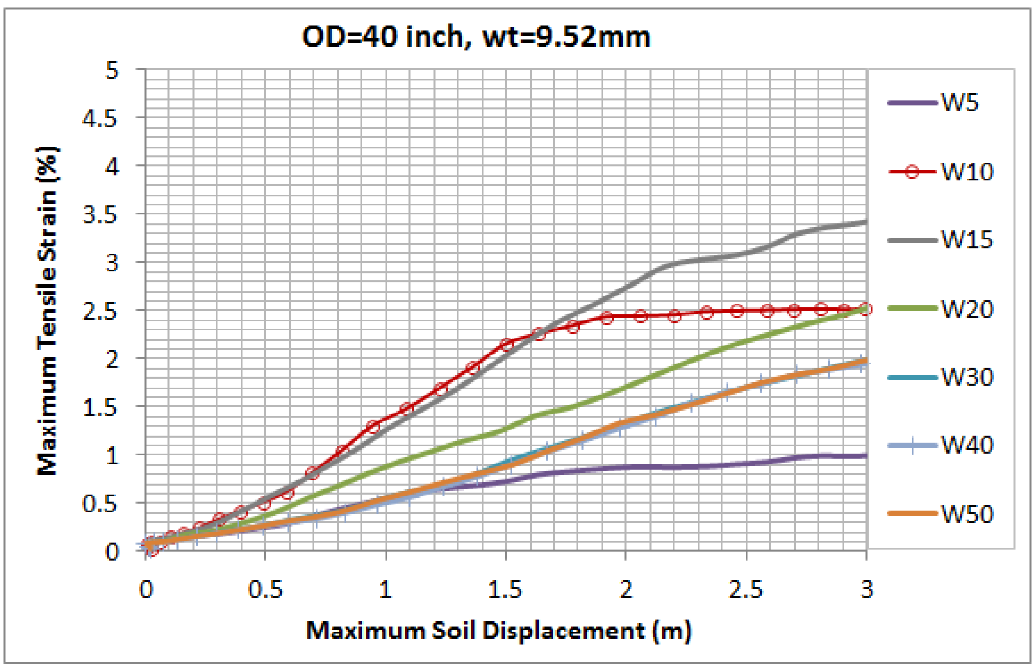

Figure 14: Calculated Tensile Strains in 40-inch Pipe Due to Lateral Soil Displacement for Lateral Ground Displacement Widths [0 – 50 m]

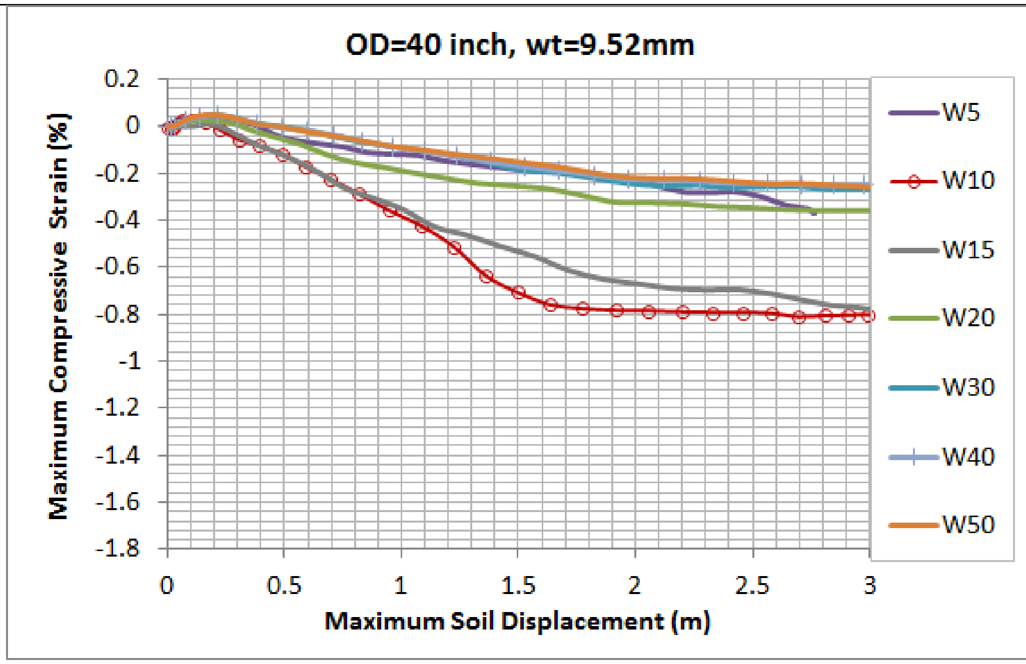

Figure 15: Calculated Compressive Strains in 40-inch Pipe Due to Lateral Soil Displacement for Lateral Ground Displacement Widths [0 – 50 m]

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

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

- The project team prepared project status reports
- Peer review meeting and presentation
- Communication with members of the project Advisory Panel to discuss project direction. A formal meeting has not been held or scheduled.

2.3 Plans for Future Activity

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

<u>Task 3: Model Development and Demonstration</u>

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.