Second QUARTERLY REPORT

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

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1.0 Technical Status

1.1 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 5th, 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 began preparation of the model validation report from previous work describing the numerical model that will support this project and its capabilities as simulation tool.

Task 3: Model Development and Demonstration

2. Modeling of Subsidence Hazard

- The project team completed the preparation of the finite element 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.

Step1-Prediction of Surface Subsidence:

The project team has progressed the development of a numerical to simulate ground deformations in subsidence events. The following provides an over view of the work to-date:

- In general the extraction width of panel in relation to the depth of mining determines the width of the subsidence area. Figure 1 illustrates the three panel extraction areas that influence surface subsidence. The panel extraction areas are defined based on panel width to mining depth ratio (W/H) as follow:
  - Sub-critical panel extraction width – occurs when the extraction width is narrow, having a W/H ratio less than 1.4, and causes less than the maximum possible subsidence at the ground surface,
  - Critical panel extraction width –is slightly wider than sub-critical and is defined as an extraction that has a W/H ratio of approximately 1.5 to 2.
  - Super-critical panel extraction width- is defined as an extraction that has a W/H ratio larger than 2.0. Super-critical extraction is large enough to potentially cause the maximum possible subsidence at the ground surface. It causes a flat area of maximum subsidence in the center of the flat surface.

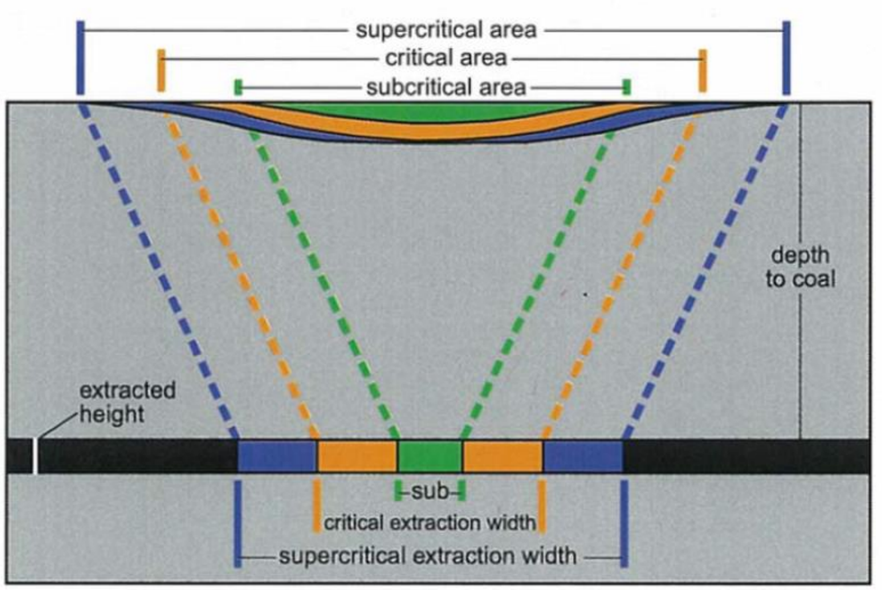

Figure 1: Long wall Mining Subsidence Parameters (after New South Wales Coal Association)

- Finite element analyses using 3D continuum model developed for this project were carried out to predict surface subsidence due to underground coal mining considering the three classified panel extraction widths (i.e., subcritical, critical and super-critical) cases.
- Three simulations were completed considering the subsidence resulting from a longwall mine face length of 300m, seam depth of 100m, extraction height of 5m, and three different extraction widths including:
    - Sub-critical panel extraction width– of W=75m that has a W/H ratio of 0.75
    - Critical panel extraction width of 150m with a W/H ratio of 1.5
    - Super-critical panel extraction width of 300 m with W/H ratio of 3.
- The subsidence profiles predicted by finite element analyses were compared with the best known empirical methods, NCB method and Appalachian methods.

Detailed results are presented as follow:

- Figure 2 through Figure 4 show examples of predicted ground subsidence using 3D continuum finite element model developed for this project. The three models presented were developed for subcritical, critical and super critical panel extraction width examples.
- Figure 5 through 7 compare the subsidence profiles predicted by the FE model and best known empirical methods, NCB Method and Appalachian method. Note 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.

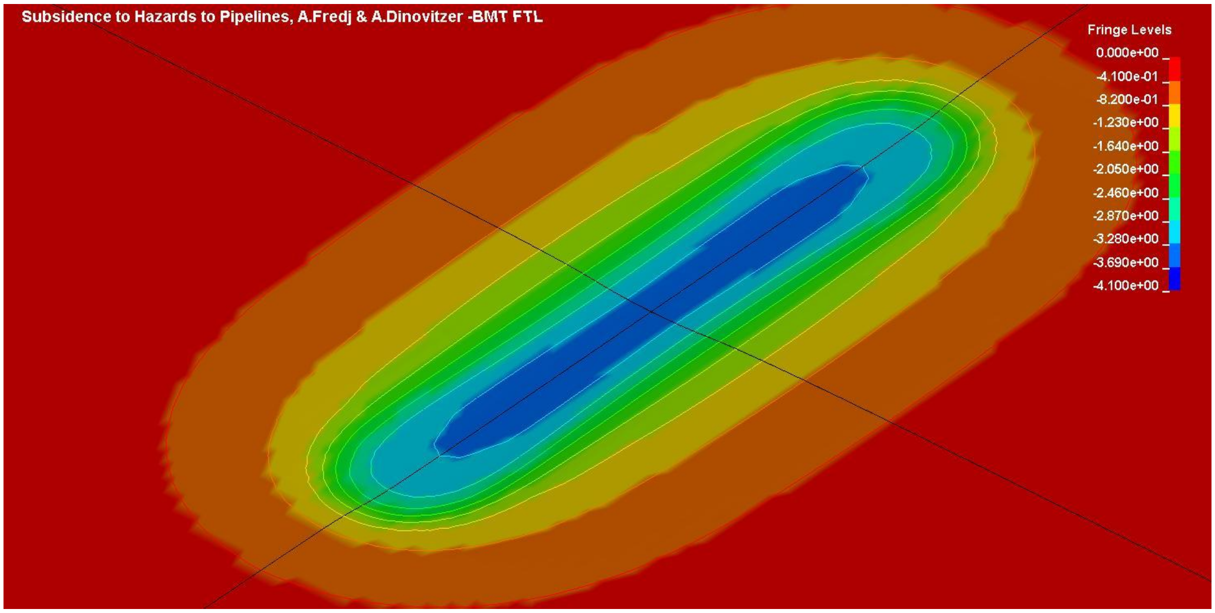

Figure 2: Ground Subsidence –Finite Element Results (subcritical panel extraction-W/H=0.75)

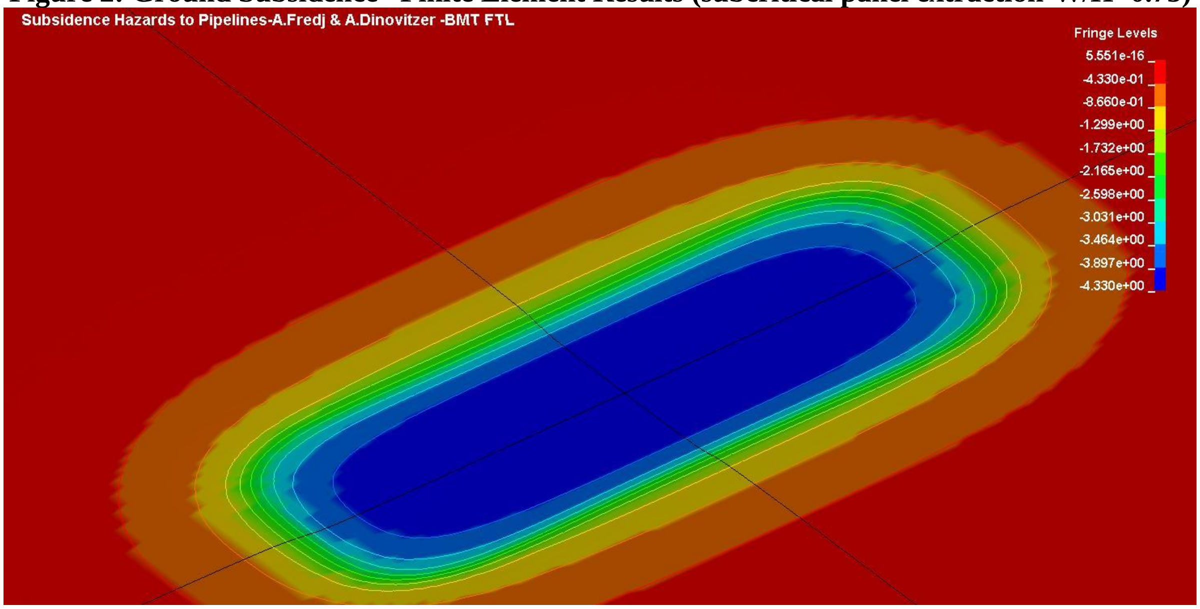

Figure 3: Ground Subsidence –Finite Element Results (critical panel extraction, W/H=1.5)

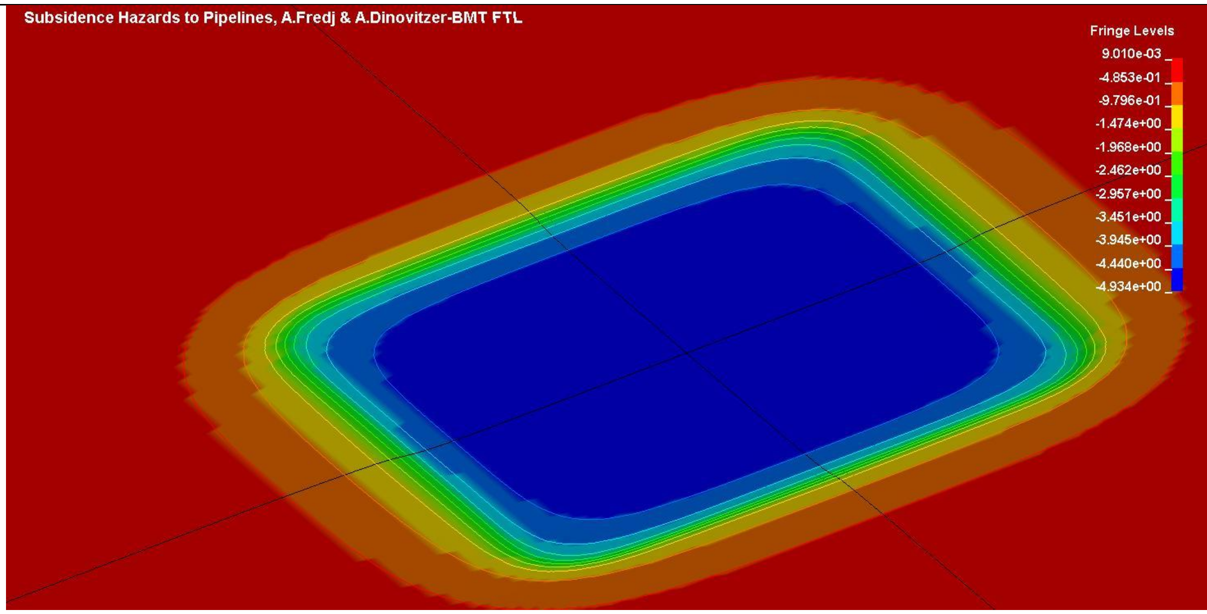

Figure 4: Ground Subsidence –Finite Element Results (Super-Critical panel Extraction, W/H=3)

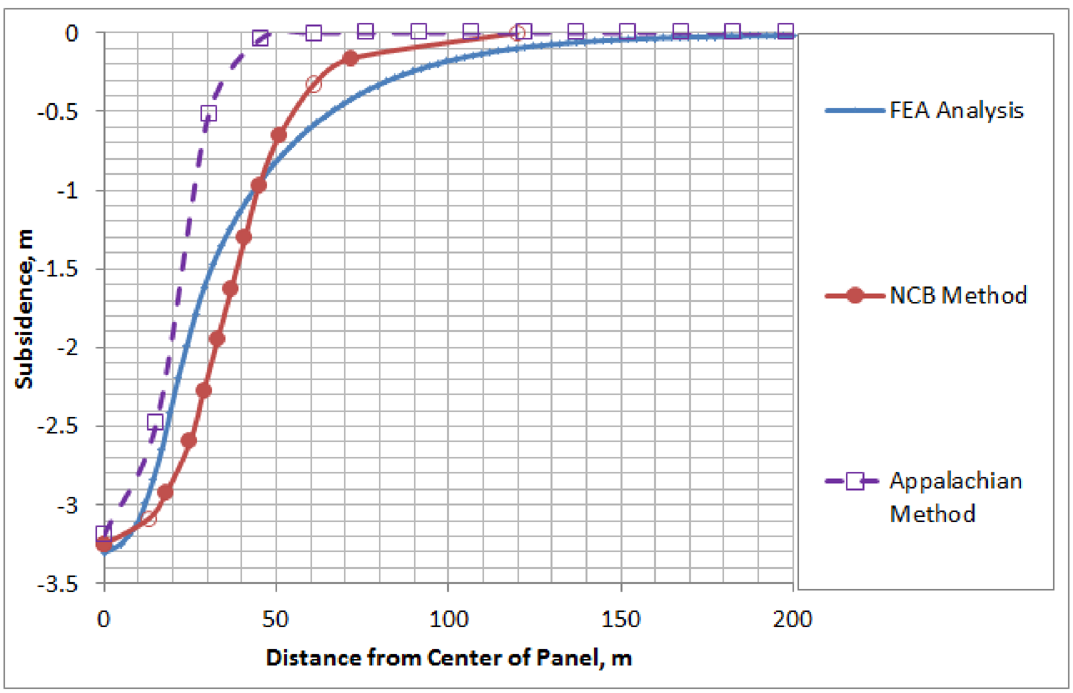

Figure 5: Comparison of Subsidence Profiles Predicted by FE model and Empirical Method (NCB Method, Appalachian Method) for Subcritical Panel Extraction Width

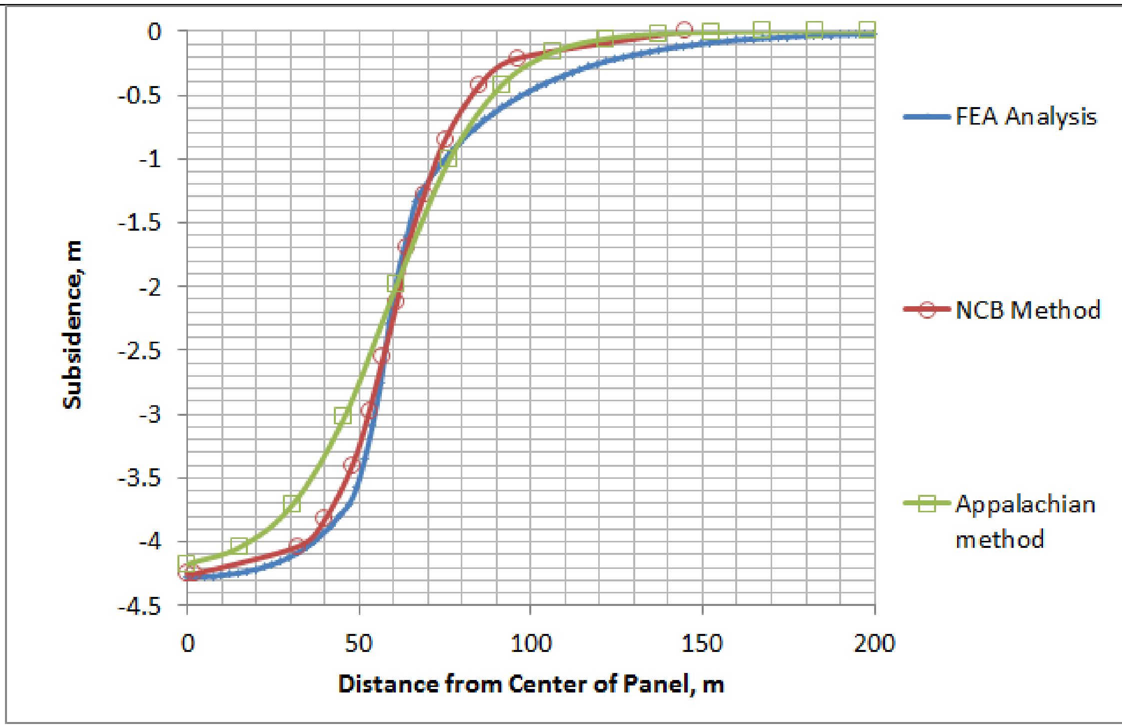

Figure 6: Comparison of Subsidence Profiles Predicted by FE model and Empirical Method (NCB Method, Appalachian Method) for Critical Panel Extraction Width

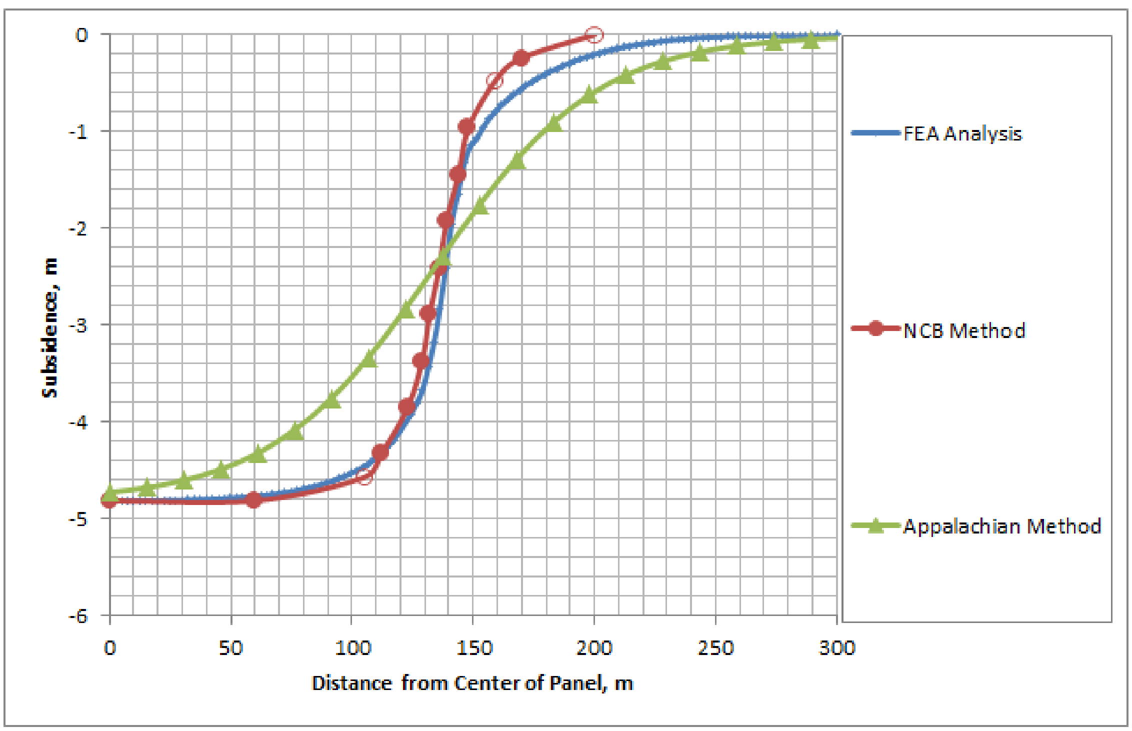

Figure 7: Comparison of Subsidence Profiles Predicted by FE model and Empirical Method (NCB Method), for Super-Critical Extraction Width

Step2: Prediction of Surface Subsidence and Effects on Pipelines.

The project team has progressed the development of a numerical model with the pipeline system explicitly represented to simulate subsidence events. The following provides an over view of the work to-date:

- 3 D continuum pipe-soil interaction models were developed to predict both surface subsidence due to coal-seam mining and its effects on pipelines.
- 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.
- Completed three subsidence simulations 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 done for 30 inch pipeline with 7.92mm wall thickness, considering the subsidence resulting from a longwall mine face length of 300m, seam depth of 100m, extraction height of 5m, and three different extraction widths including:
  - Case1: Sub-critical panel extraction width– of W=75m that has a W/H ratio of 0.75
  - Case2: Critical panel extraction width of 150m with a W/H ratio of 1.5
  - Case3: Super-critical panel extraction width of 300 m with W/H ratio of 3.

  Detailed results are presented as follow:

  - Figure 8 shows an examples of predicted ground subsidence and pipe deformation for case1 considering subcritical extraction width (W/H=0.75). In this Figure the pipe backfill trench continuum is hidden so that the displaced pipeline can be visualized.

  - Figure 9 shows an example of the predicted ground subsidence and pipe deformation for Case2 considering critical extraction width (W/H=1.5). In this Figure the pipe backfill trench continuum is hidden so that the displaced pipeline can be visualized.

  - Figure 10 shows an example of the predicted ground subsidence and pipe deformation for Case3 considering critical extraction width (W/H=3). In this Figure the pipe backfill trench continuum is hidden so that the displaced pipeline can be visualized.

  - Figure 11 plots 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 this Figure are for Case1 considering a sub-critical extraction width (W/H ratio of 0.75).

  - Figure 12 plots 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 this Figure are for Case2 considering a critical extraction width (W/H ratio of 1.5).

  - Figure 13 plots 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 this Figure are for Case3 considering a Super-critical extraction width (W/H ratio of 3).

In all of the plots (Figure 11 to 13) of pipe strain, the model includes some small variations in strain associated with numerical oscillations which will need to be resolved or filtered in the future.

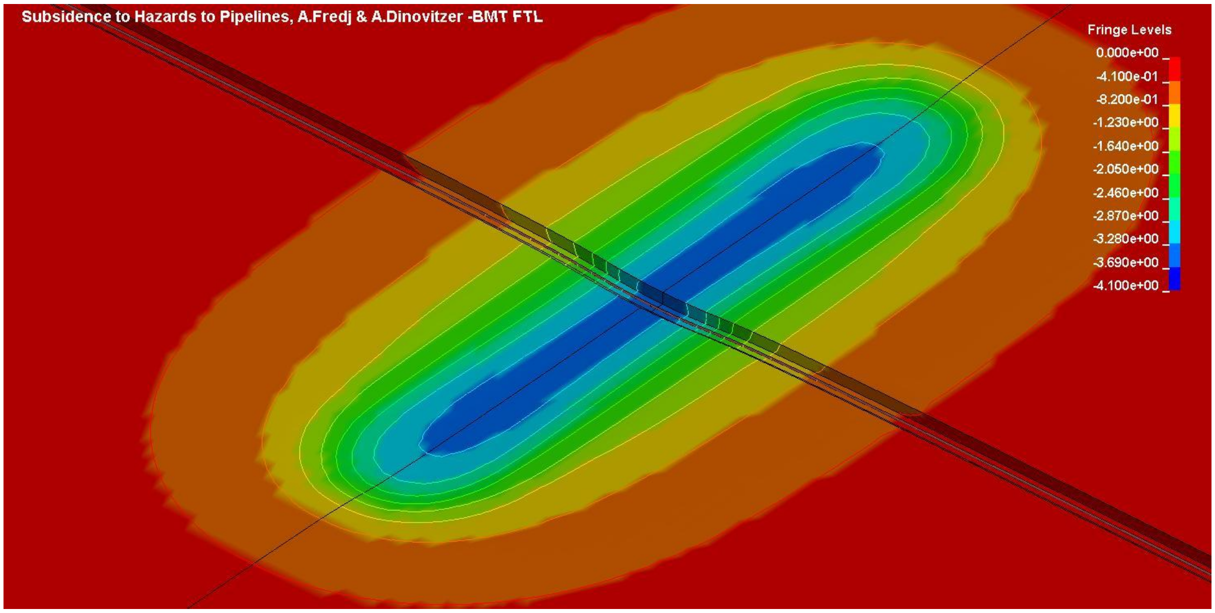

Figure 8: Surface Subsidence and pipeline deformation, for Case2: Subcritical Extraction Width, W/h=0.75

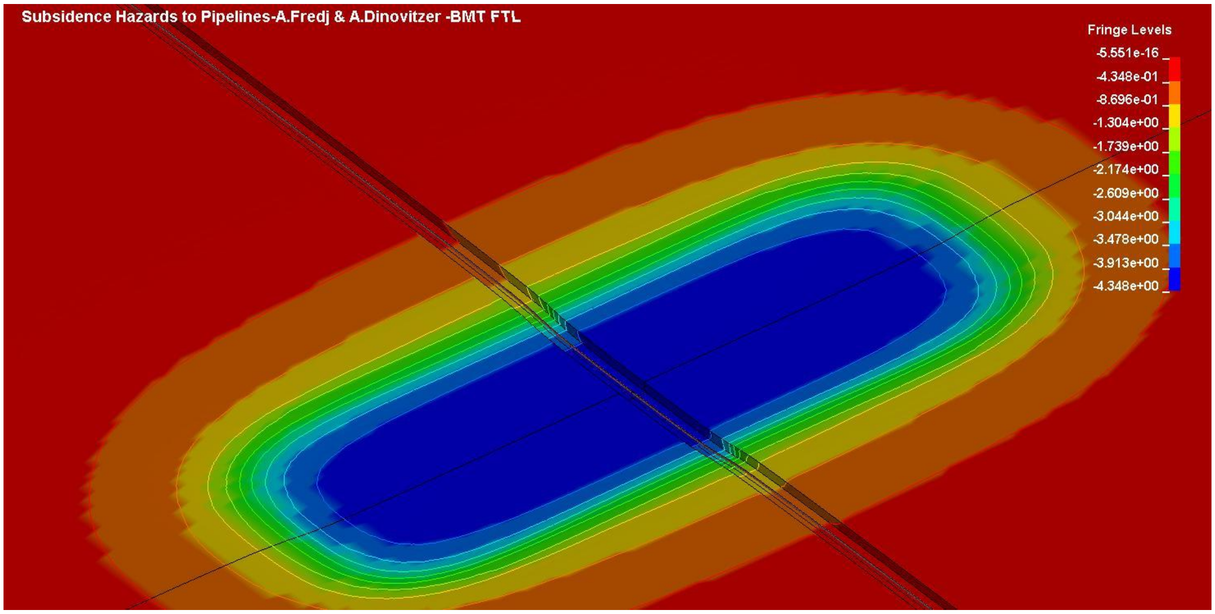

Figure 9: Soil Subsidence and pipeline deformation, for Case2: critical Extraction Width, W/h=1.5

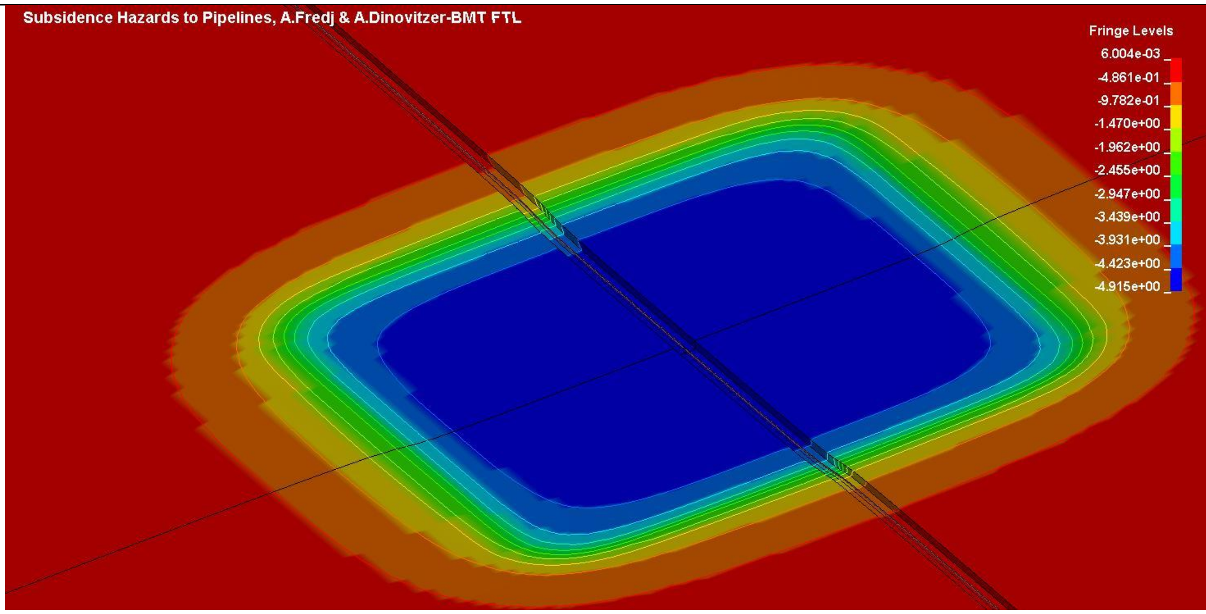

Figure 10: Soil Subsidence and pipeline deformation, for Case3: Super-Critical Extraction Width, W/h=3

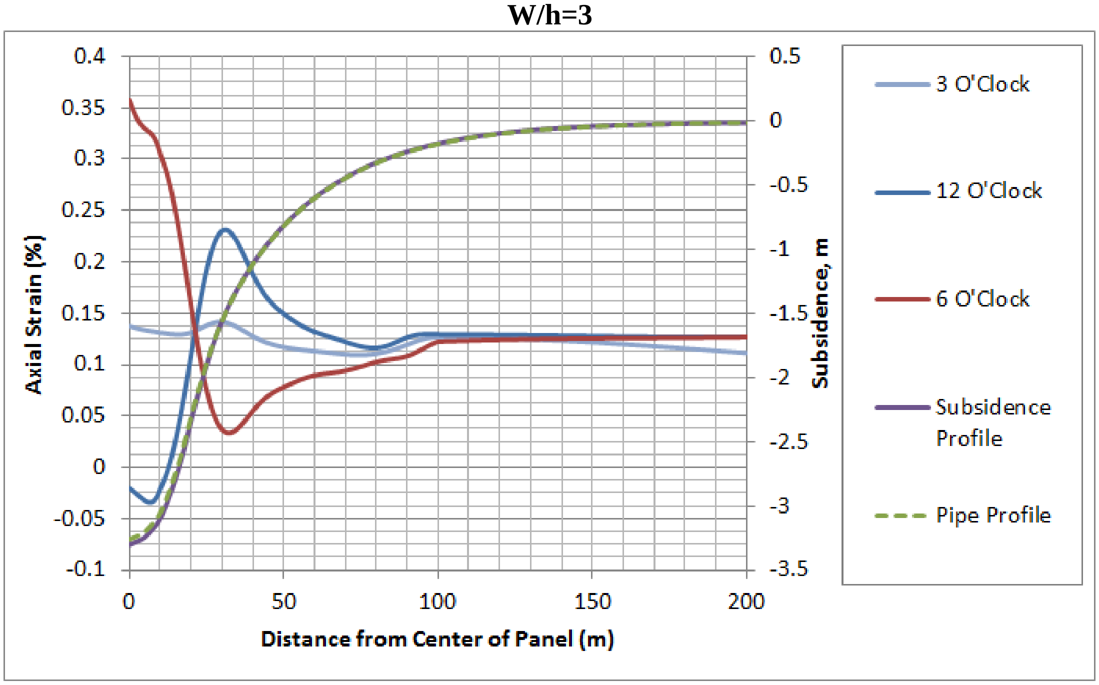

Figure 11: Surface Subsidence, Pipeline profile and Axial strains Distribution, for Subcritical Extraction Width (W/h=0.75) – Case1

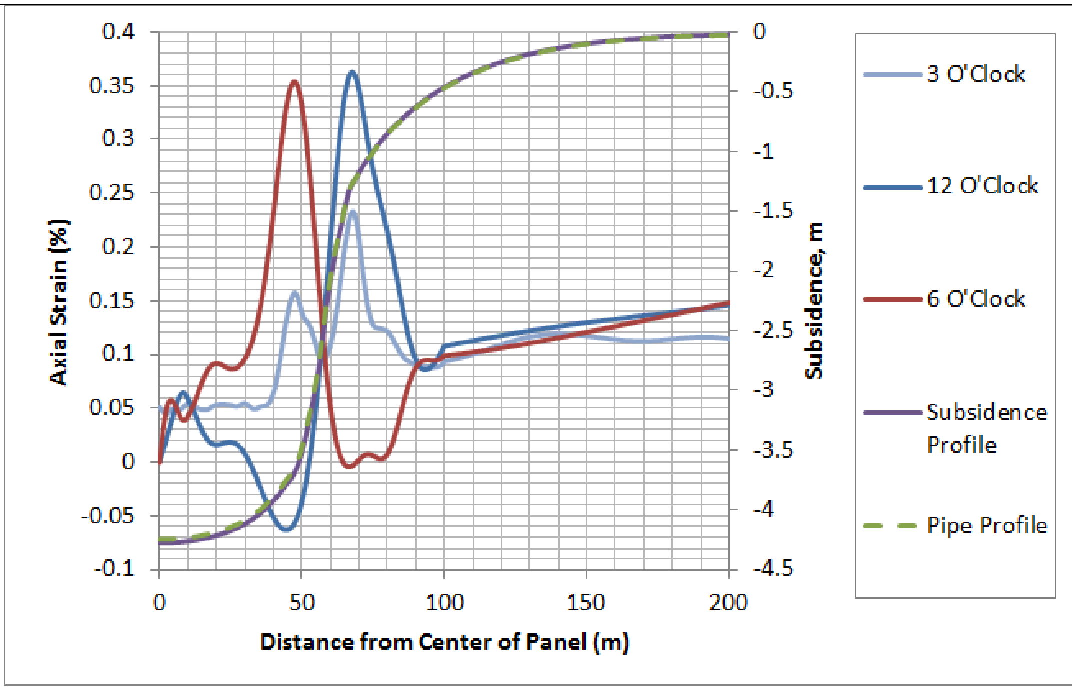

Figure 12: Surface Subsidence, Pipeline profile and Axial strains Distribution, for Critical Extraction Width (W/h=1.5) - Case2

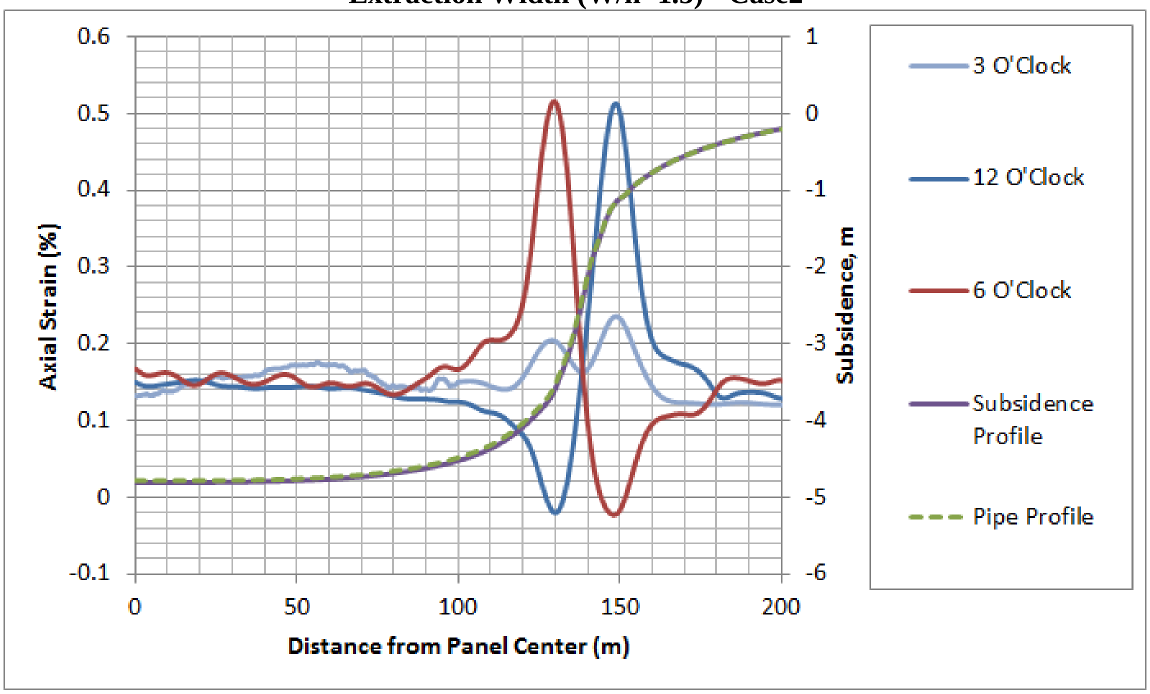

Figure 13: Surface Subsidence Pipeline profile and Axial strains Distribution, for Super Critical Extraction Width (W/h=3) - Case3

3. 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 done for a 30 inch pipeline with a 7.92mm wall thickness, considering three lateral soil movement widths including:
  - Case1: W= 10m
  - Case2: W= 20m
  - Case3: W= 40m

- The following Figures illustrate the SPH Finite element model and snapshots of the finite element model output.
  - Figure 14 illustrate the SPH Finite element model including the pipe in an elevation view. Figure 15 illustrates the model in plan view demonstrating the lateral movement of the soil where the pipeline trench backfill is the pink material.
  - Figure 16 illustrates the response of pressurized pipeline subjected to ground movement for Case1 (W = 10m). Figure 16 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 17 illustrates the response of pressurized pipeline subjected to ground movement for Case2 (W = 20m). Figure 17 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 18 illustrates the response of pressurized pipeline subjected to ground movement for Case3 (W = 40m). Figure 18 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 19 illustrates an example of ground movement profile at different levels of movements considering movement width of 20m (Case2). 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 20 illustrates an example of pipeline deformation profile at different levels of ground movement considering ground movement width of 20m (Case2). These results compared with those in Figure 19 illustrate that the pipe does not follow the same profile since some of the soil flows around the pipe.
  - Figure 21 shows the true axial strain at 3'oclock and 9 o'clock position along the pipeline for case1 (W=10m) considering soil movement of 1.93m
  - Figure 22 shows the true axial strain at 3'oclock and 9 o'clock position along the pipeline for case2 (w=20m) considering soil movement of 1.93m

- Figure 23 shows the true axial strain at 3'oclock and 9 o'clock position along the pipeline for case3 (w=40m) considering soil movement of 1.93m

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 10m to 20m for the 30 inch pipeline. A sensitivity analysis is being carried and more details will be provided in the next progress report.

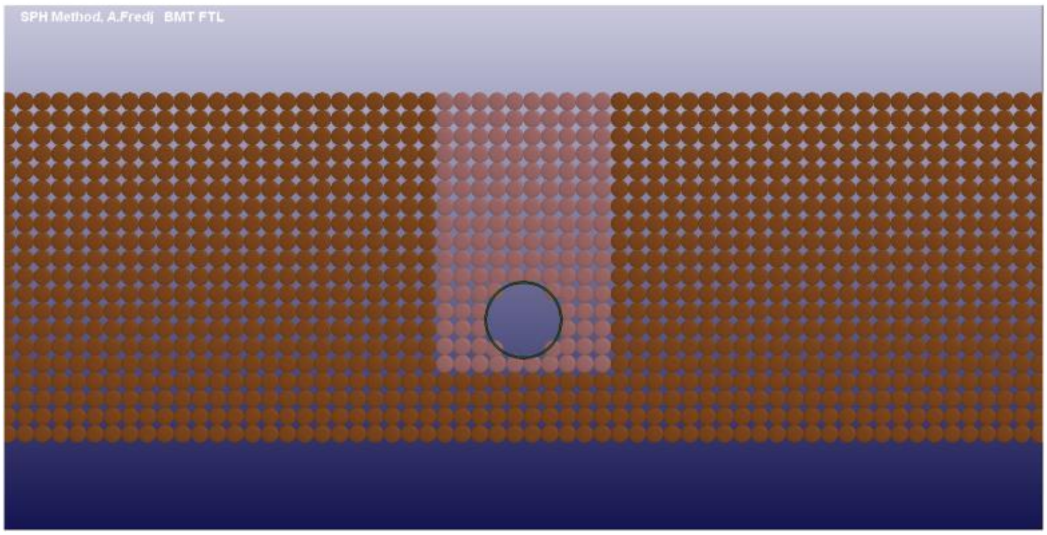

Figure 14: Illustration of the SPH FE Model Including the Pipe-side view

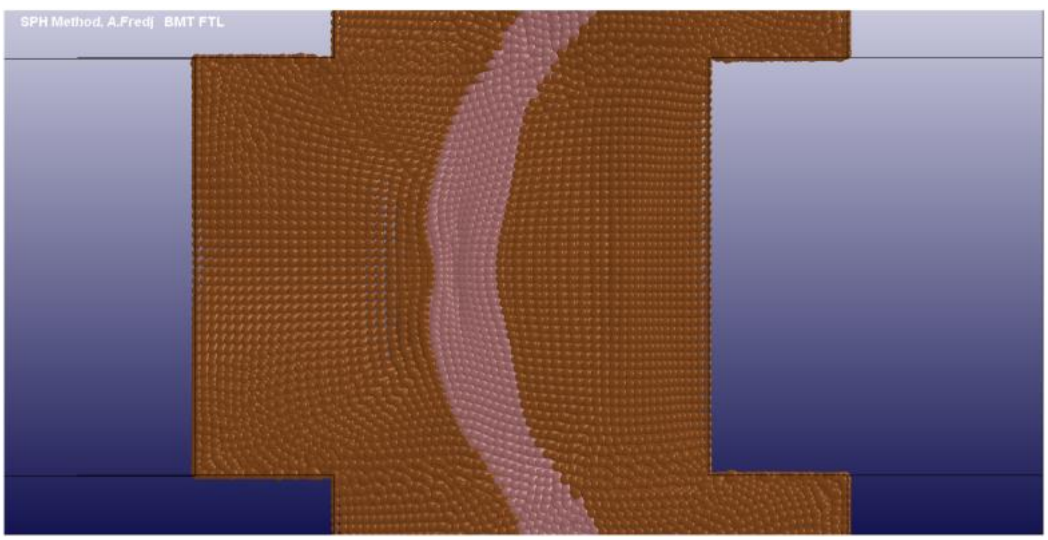

Figure 15: Illustration of the SPH FE Model Simulation

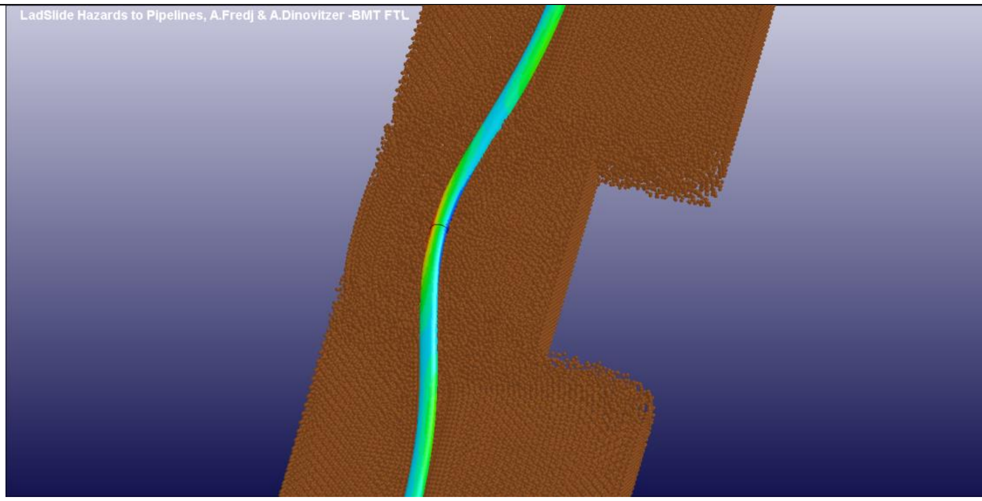

Figure 16: Pipe Deformation & Axial Strain (blue compressive and red is Tensile) For Case1: Soil Movement of 4.9m & Width= 10m

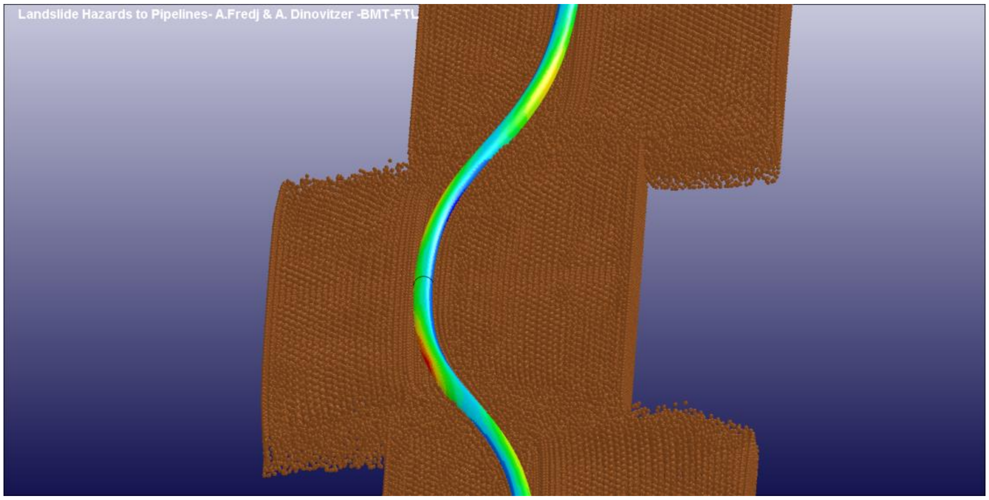

Figure 17: Pipe Deformation & Axial Strain (blue compressive and red is Tensile) For Case2: Soil Movement of 4.9m & Width= 20m

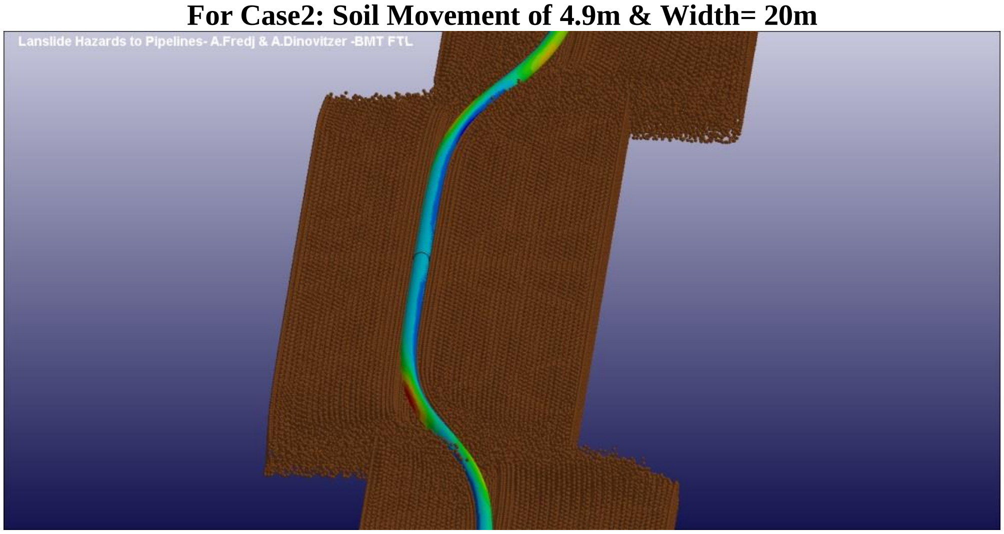

Figure 18: Pipe Deformation & Axial Strain (blue compressive and red is Tensile) For Case3: Soil Movement of 4.9m & Width= 40m

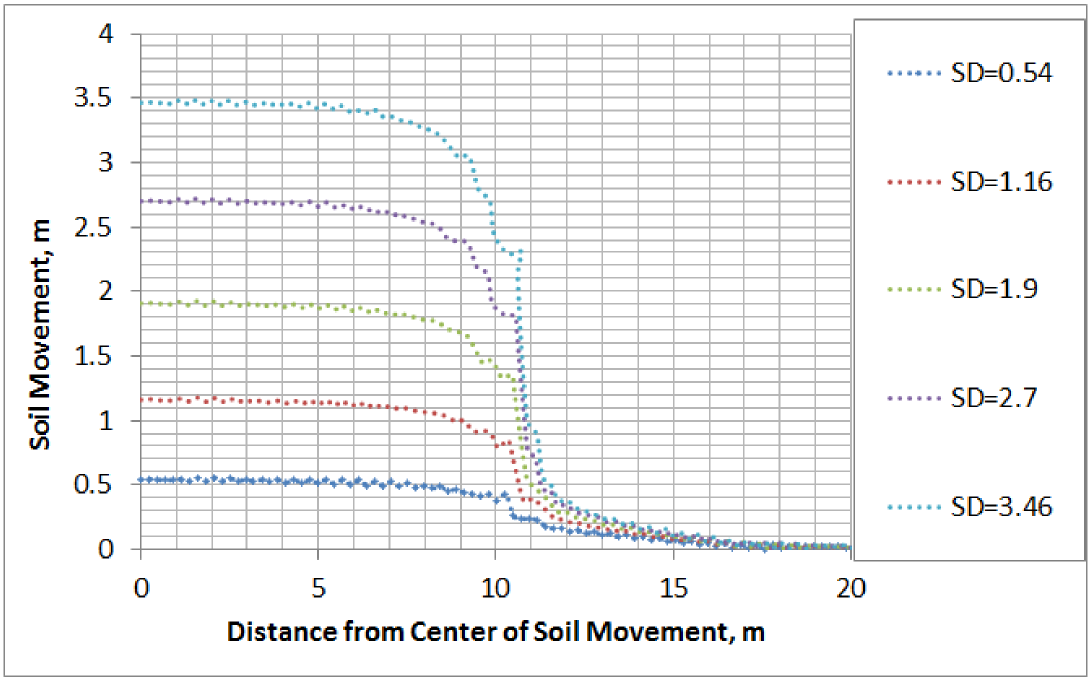

Figure 19: Ground Movement Profiles at Different Levels of Soil Movement for Case2: W=20m

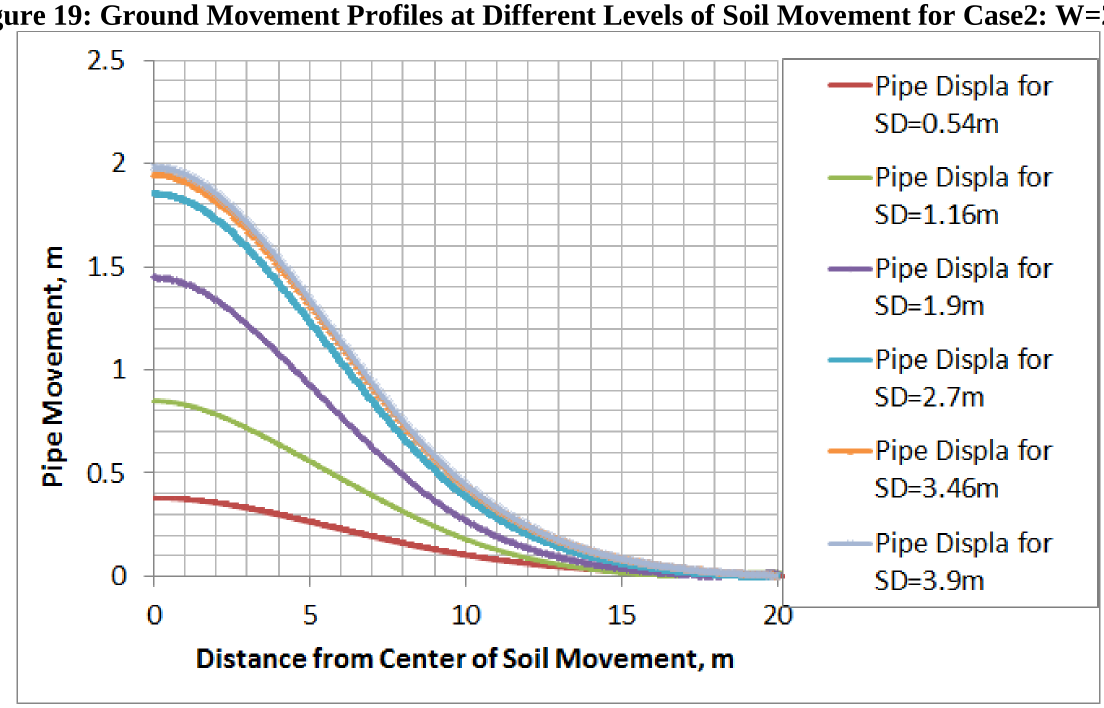

Figure 20: Pipe Movement Profiles at Different Levels of Soil Movement for Case2: W=20m

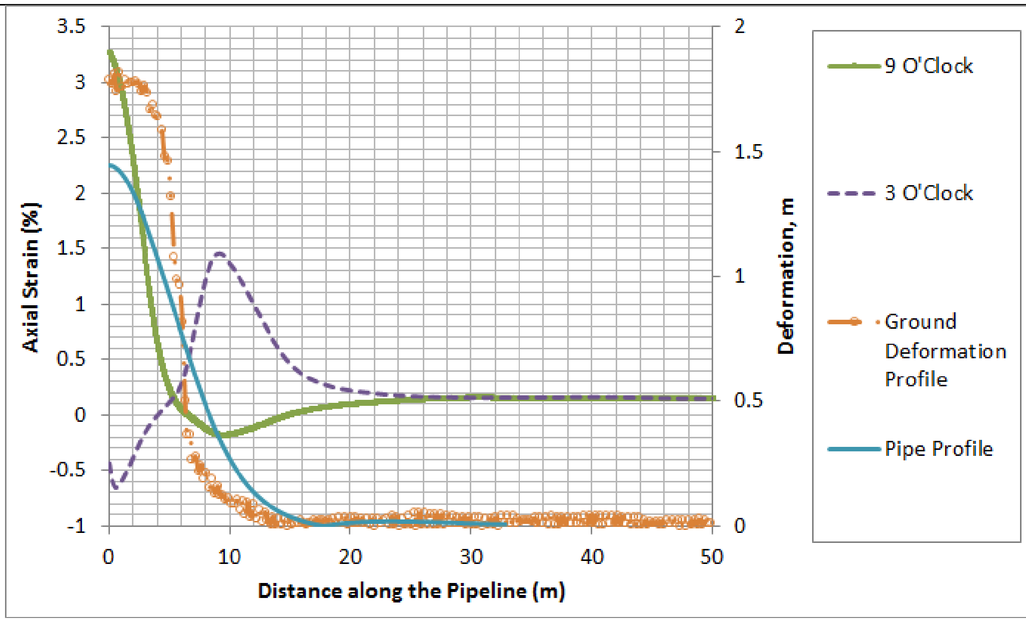

Figure 21: Axial Strain & Pipe and Ground Movement Profiles for Case1: W=10m Considering Soil Movement of 1.93m

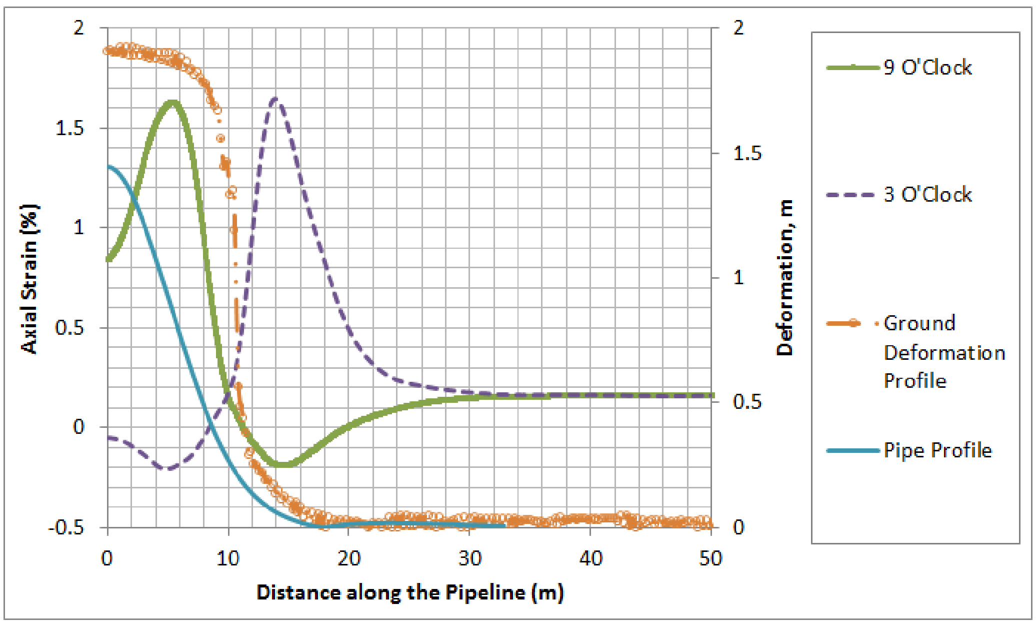

Figure 22: Axial Strain & Pipe and Ground Movement Profiles for Case2: W=20m Considering Soil Movement of 1.93m

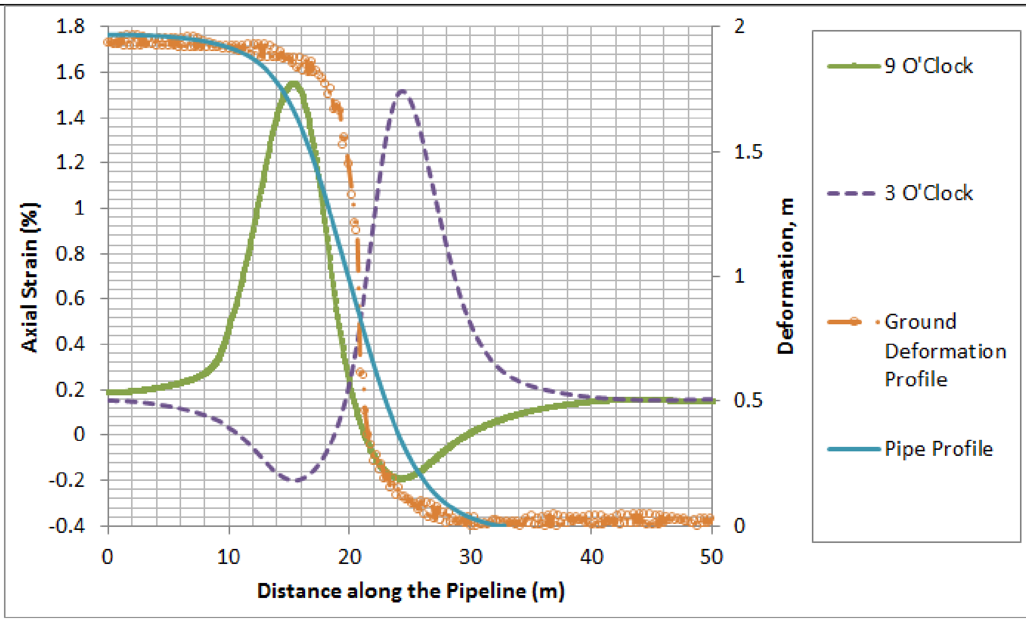

Figure 23: Axial Strain & Pipe and Ground Movement Profiles for Case3: W=40m Considering Soil Movement of 1.93m

<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:

Task 3: Model Development and Demonstration

- Project team will complete the post-processing of the analyzed cases and evaluate the results.
- The strain demand determined from the analyses will be compared with the calculated BS 7910 strain limit, CSA-Z662 strain limit design, API RP1111-Limit State Design, and local buckling analyses
- 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 7: Project Management and Reporting

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