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Pipeline integrity subjected to large seismic induced PGD

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1 INTRODUCTION & SCOPE OF WORK

Plastic strain in pipelines already in service may be acceptable, provided a thorough engineering investigation and safety management study demonstrates that the strain does not significantly increase the risk of failure. The present paper presents an investigation of an existing 32” gas and 8” condensate pipeline subjected to several seismic induced landslides. The design pressure is 170 bars of the gas pipeline and 255 bars of the condensate pipeline. Figure 1 shows a typical landslide area and a rock fall along the RoW. The soil type in the landslide areas is mainly clay over volcanic bedrock.

Figure 1. *Landslide and rockfall along RoW*

2 METHODOLOGY

The stress analysis was based on principles of the PRCI Guidelines for Constructing Natural Gas and Liquid Hydrocarbon Pipelines through Areas Prone to Landslide and Subsidence Hazards (2009) and PRCI Guideline for Strain-Based Design (2011). The geometrically and materially non-linear pipe stress analyses were conducted with ABAQUS Standard (landslides) and ABAQUS Explicit (rockfall) software.

Overmatching welds are a requirement for the strain-based design concept (weld metal overmatching pipe metal, Charpy energy >40J, CTOD toughness >0.2 mm, yield strength to tensile strength ratio <0.92). Different tensile and compressive strain limits are defined in various standards (CSA Z662, ASCE, PRCI, EN 1998-4). A testing program was conducted to evaluate the strain capacity of the base material and the girth welds (strain capacity, flaw acceptance criteria, SENT tests). Stress-strain curves according to the test results were used for the stress analysis (Figure 2).

The post-earthquake displacements of the 32” and 8” pipelines at the landslide areas were surveyed by the line-finder method. Pipeline displacements up to 1.5 m were surveyed. Displacement vectors (Easting, Northing and Elevation components) for the stress analysis were derived from the difference of the surveyed line-finder data to the as-built pipeline coordinates (Figure 5).

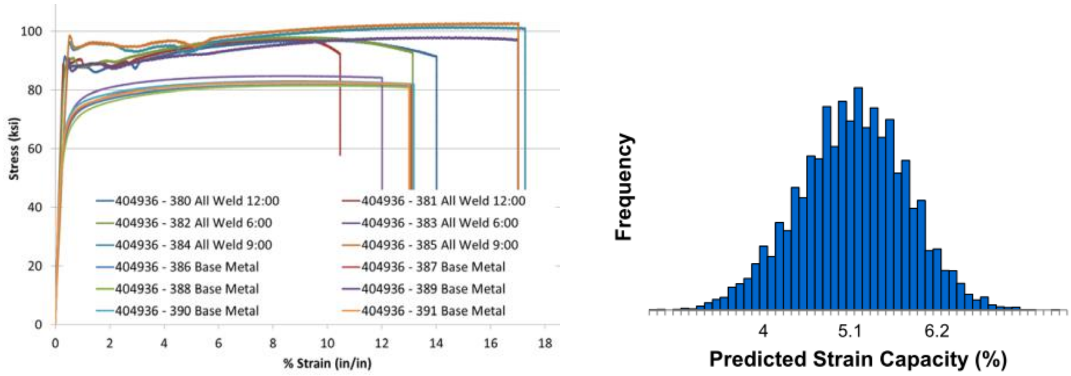

Figure 2. *Stress strain curve and predicted strain capacity of test results*

3 RESEARCH OUTCOMES

The analysis parameters (pipeline alignment, soil cover etc.) for the stress analysis are based on as-built data. The plan and profile view of a typical analysis model with a length of 3 km is shown in Figure 4. Element types PIPE31 are used for straight pipeline sections, ELBOW31 for field and induction bends and PSI34 for the pipe-soil interaction. The pipe-soil interaction elements are non-linear springs in axial, lateral and vertical up/down direction along the pipeline. The non-linear spring parameters are based on the PRCI Guideline (2009). The pipe-soil interaction elements are defined by the nodes of the pipeline and the nodes of the ground surface. The ground displacement (landslide) is applied at the nodes of the ground surface. The displacement vector of each node of the ground surface is based on the survey data according to Figure 5. Complete ABAQUS inputfiles are created in one step by pre-processing software (Excel VBA scripts) based on as-built data from pipeline tally and the landslide survey data. Separate analyses are conducted for the 32” and 8” pipelines. A possible interaction of the pipelines is not considered.

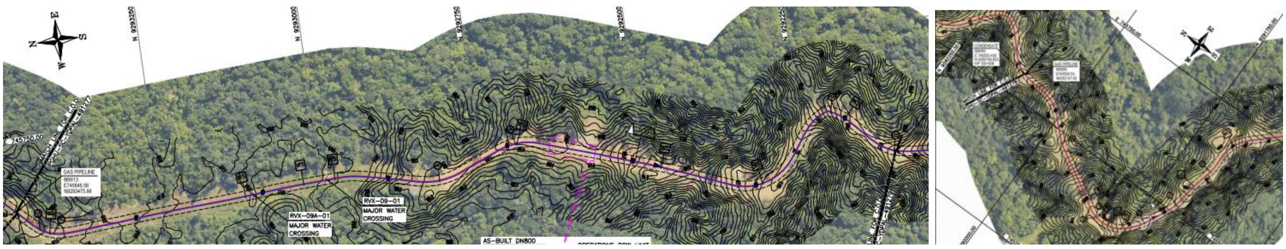

Figure 3. *Alignment sheet*

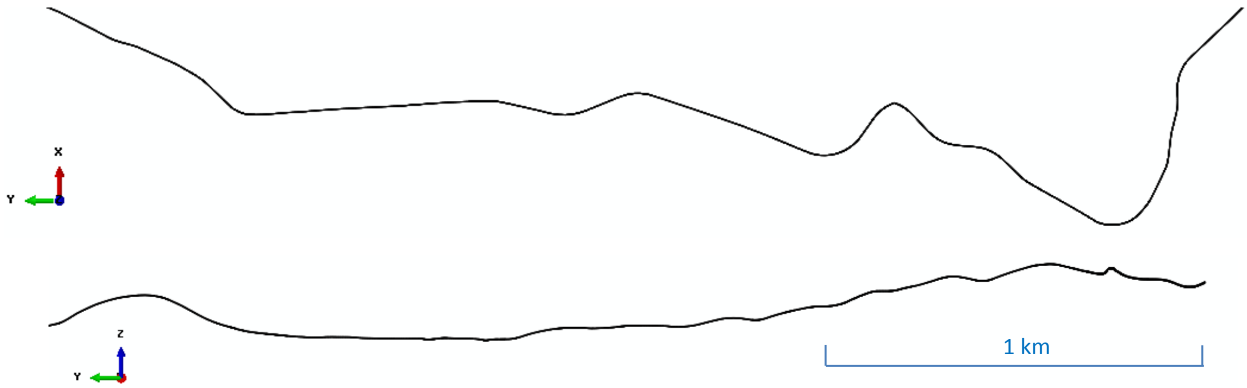

Figure 4. *Plan and profile view of a typical analysis model, length 3 km*

The pipe stress analysis results are summarized by axial strain vs. ground displacement diagrams for the decisive locations of the pipeline (Figure 5). Post-processing software is used to derive the strain vs. ground displacement diagrams from the ABAQUS result files. In total six landslide areas are investigated.

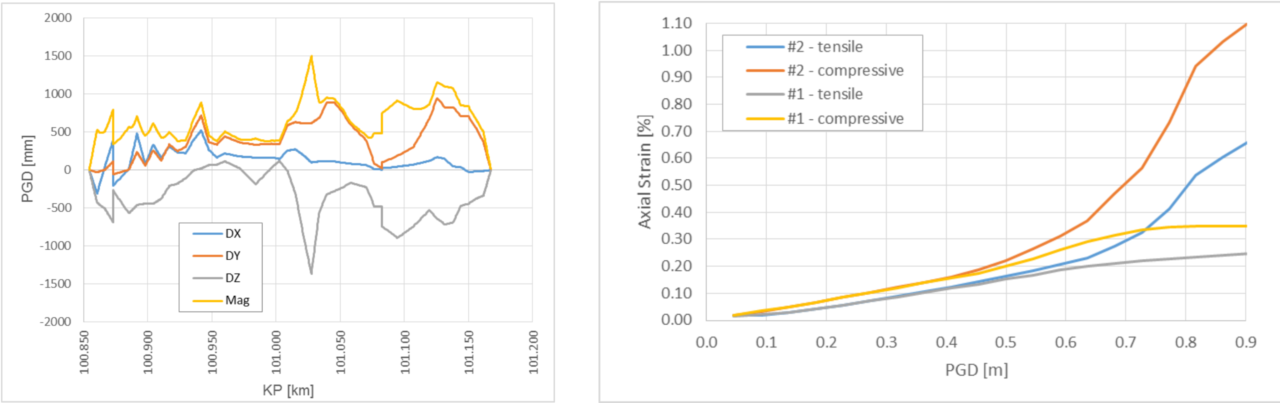

Figure 5. *Typical displacement vector diagram and axial strain vs. ground displacement diagram*

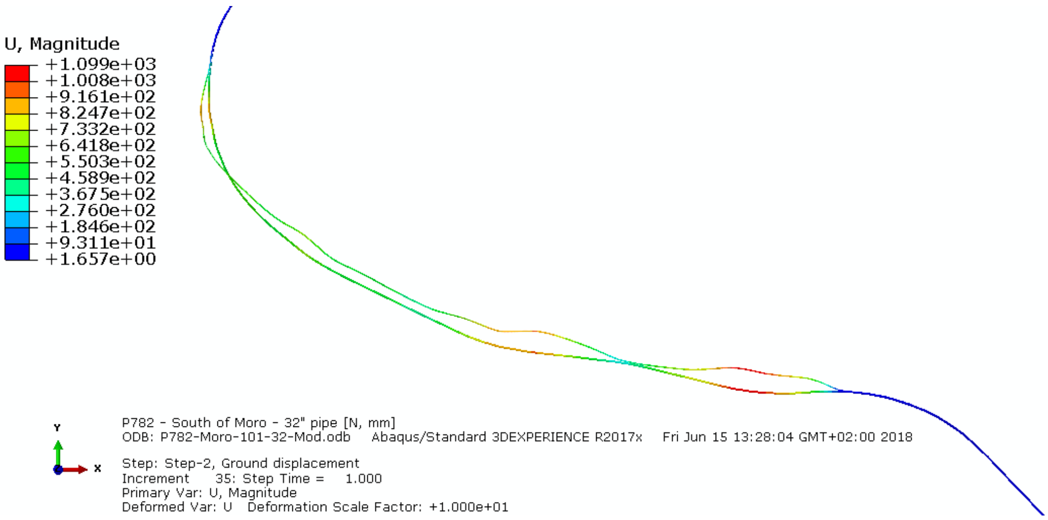

Figure 6. *Plan view of undeformed and deformed pipeline section*

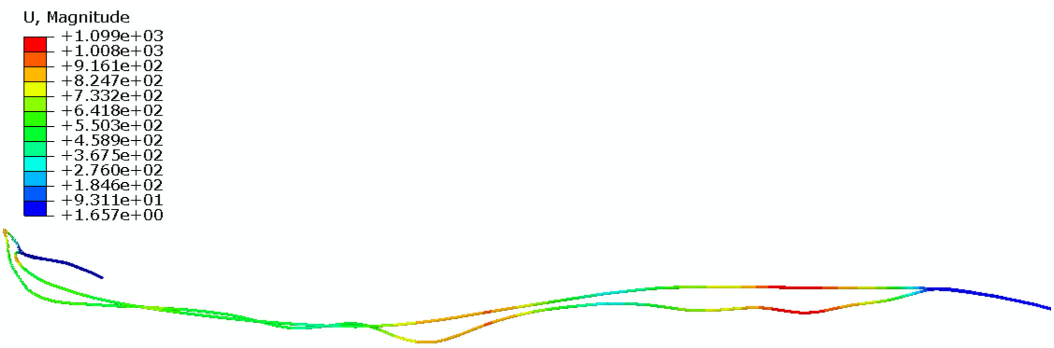

Figure 7. *Profile view of undeformed and deformed pipeline section*

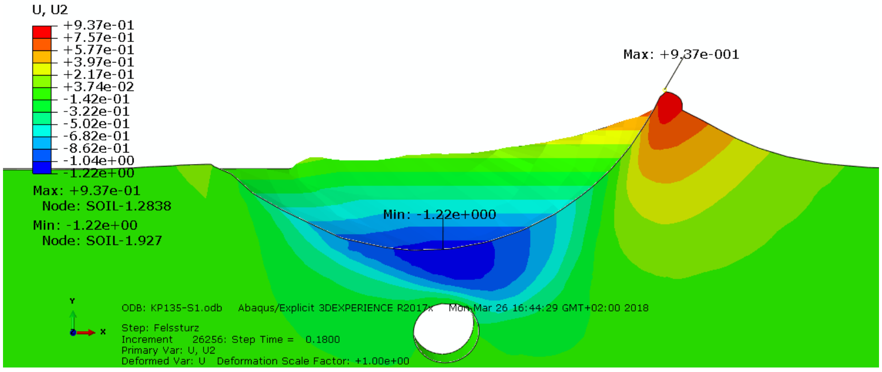

Figure 8. *Section view of rockfall impact location*

The construction of micro-piles, connected with steel ropes as shown in Figure 9, was chosen as an appropriate mitigation measure to avoid future landslides along the RoW. The system piles-pipelines-soil is performing as one block; thus achieving its stabilization in case of a landslide from either one side of the RoW. In addition a stabilization of the soil itself is to be expected, since the steel ropes act as reinforcing means to a certain extend. The method is considered to be an innovative approach to similar problems, experimental testing is to be performed prior to construction.

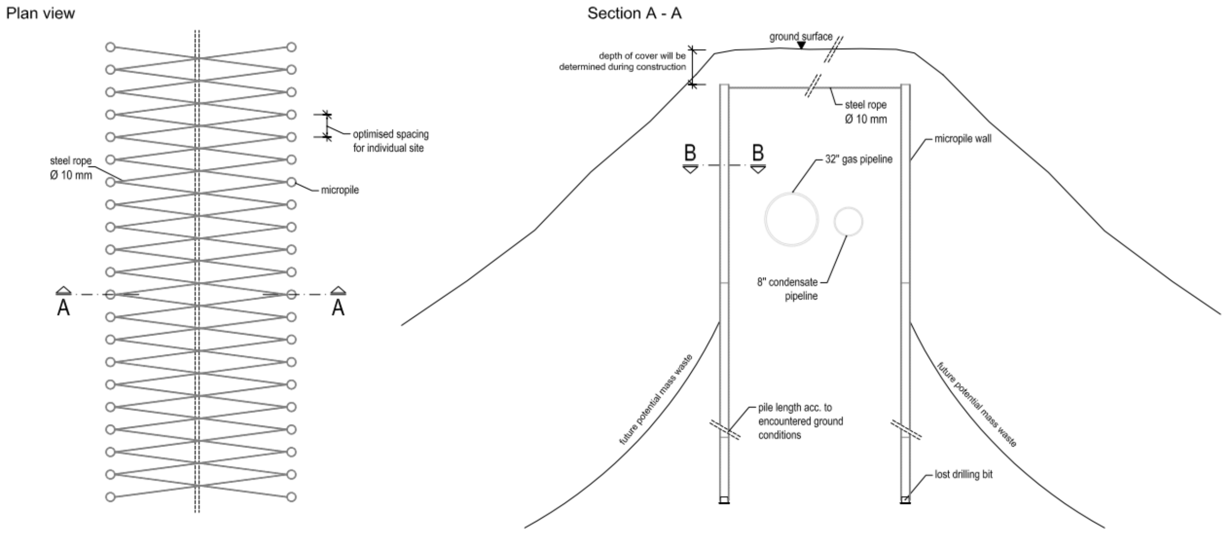

Figure 9. *Micropiles along RoW*