STRUCTURAL INTEGRITY MANAGEMENT IN HYDROCARBON TRANSPORTATION PIPELINES BASED ON SOIL-PIPELINE INTERACTION, APPLICATION CASE: OCENSA

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Cause: Geological and geotechnical instability

Effect: Deformation and bending of pipelines

GENERAL CONTEXT

Geotechnical Criteria

Alerts	
Displacements (cm)	Importance
>30	1
30 to 20	2
20 to 10	3
< 10	4

Mechanical Criteria

Increase in bending strain from baseline (greater between Compression and Tension) = E	Presence of stress concentrators (changes in thickness, dents, ripples, scratches and/or metal loss)	Rating	Risk assessment matrix				
TC/CC<E	Yes	E	Moderate	High	High	High	Extreme
TA/CA<E<TE/CE	Yes	D	Moderate	Moderate	High	High	High
	No	C	Low	Moderate	Moderate	High	High
0,2%<E<TA/CA	Yes	B	Low	Low	Moderate	Moderate	Moderate
	No	A	Low	Low	Low	Low	Moderate

Low correlation between criteria

SOIL PIPE INTERACTION: MECHANICAL AND GEOTECHNICAL WORLD MEETING

- Relevant piping parameters:
  - Elastic Modulus (*E*);
  - Diameter (D);
  - thickness (t);
  - Inertia (*I*)
  - Depth (d);
  - Radius of curvature (*R*);
  - Operating pressure (OP);

- Relevant soil parameters :
  - Elastic Modulus(*E*);
  - Cohesion (*c*);
  - Friction Angle (ϕ)

Inertial Tools (ILI)

Topographic Monitoring

Subsurface Research

Mechanical Deformation Criteria

Solid Mechanics (discrete)

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Coupled Models

↑

Continuous Medium Mechanics

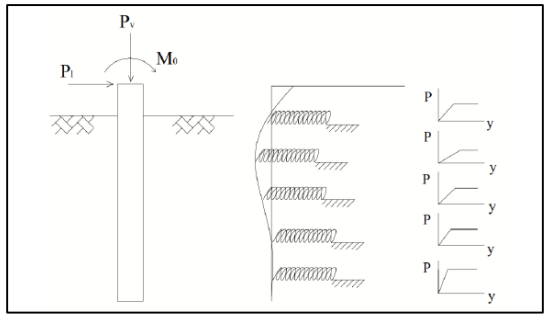
Criteria Displacement Ground

SOIL PIPE INTERACTION: METHODS AND MODELS OF ANALYSIS

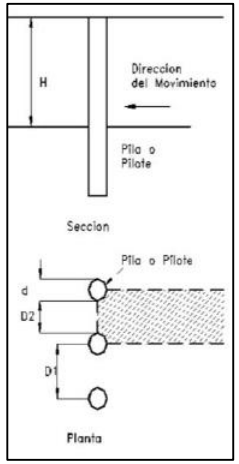
Uncoupled Methods (Load-Load and Deformation Methods):

- Itoy Matsui(1975);
- Brandl(1977,1933);
- Viggiani(1981);
- Broms(1981);
- NAVFAC (1986);
- Pearlman*et al.*(1992);
- Kumary Hall (2006);
- p-y (Poulos1971);
- Hassiotis*et al.* (1984);
- Ashour(1998)

Analytical Models;
Continuous Medium;
Short Structure



Curvas p-y (Poulos)

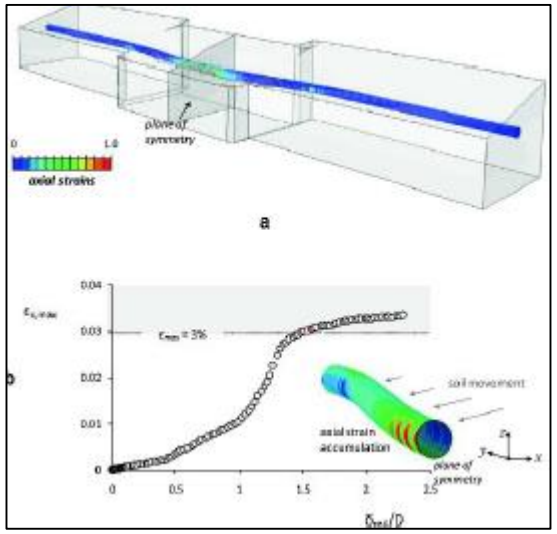


Itoy Matsui

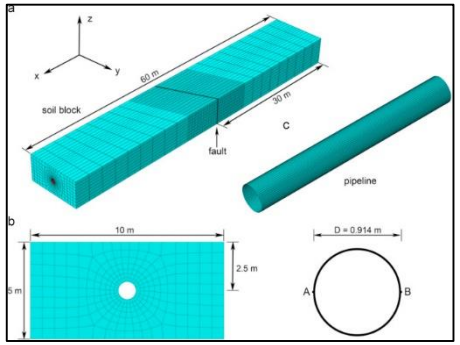
Coupled Methods (Finite Element Method):

-Liangy Zeng(2000);
-Caiy Ugai(2000);
-Yamin(2007);
-Al Bodour(2010);
-Liuet al. (2010);
-Kourkoliset al. (2011);
-Kahyaogluet al. (2012);

Numerical Models;
Discrete Elements;
Long structure;
Internal Pressure



Finite Elements



SOIL PIPE INTERACTION: ADAPTATION OF THE FINITE ELEMENT METHOD (FEM) TO SOIL-PIPE INTERACTION

1. GEOMETRY GENERATION
- Piping, soil and fluid data input template generation (including internal and external corrosion).
- Generation of deformation parameters template in anomalies through displacement nodes.

2. CONCEPTUAL MODEL
- Definition of parameters such as applied loads, materials and definition of intervals of the decoupled sub models:
  - Pipe sub model
  - Soil sub model
  - Hydraulic sub model
- Definition of interaction parameters between the decoupled models and interaction sensitivity analysis.

3. MATHEMATICAL MODEL
- Definition of load ranges for each sub model.
- Type of material behavior for each sub model.
- Type of contact and contact parameters between sub models.

Modeling

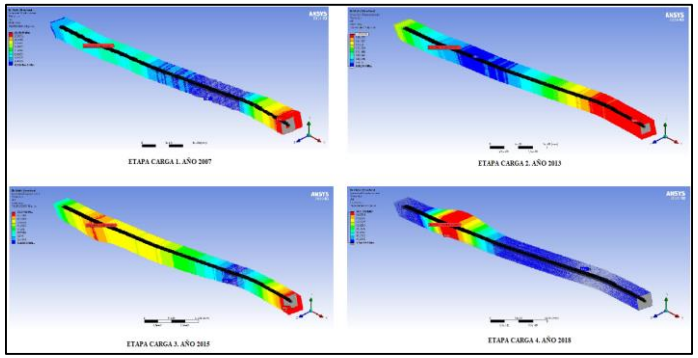
4. COMPUTATIONAL MODEL
- Definition of degrees of freedom.
- Boundary and contact conditions
- Governing equations
- Convergence criteria
- Definition of expected results, graphs and maps.

Pre and Post Process

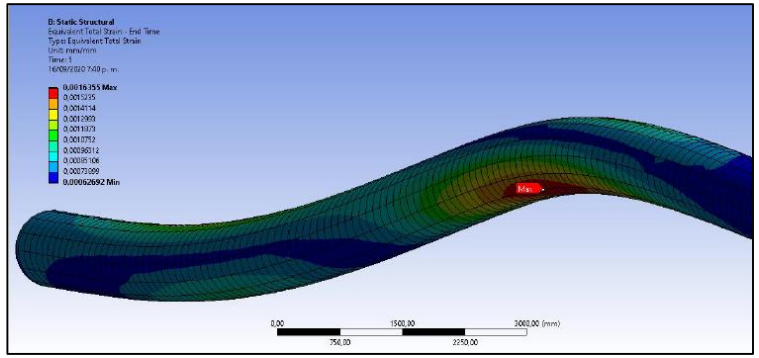
5. VERIFICATION
- The accuracy of the results delivered by the computational model is checked and reported with respect to the mathematical model, through the estimation of the error of the algorithm of the software used (Ansys).

6. VALIDATION
- The comparison is made with experimental data, according to the accuracy criteria defined by the client to make the model acceptable.

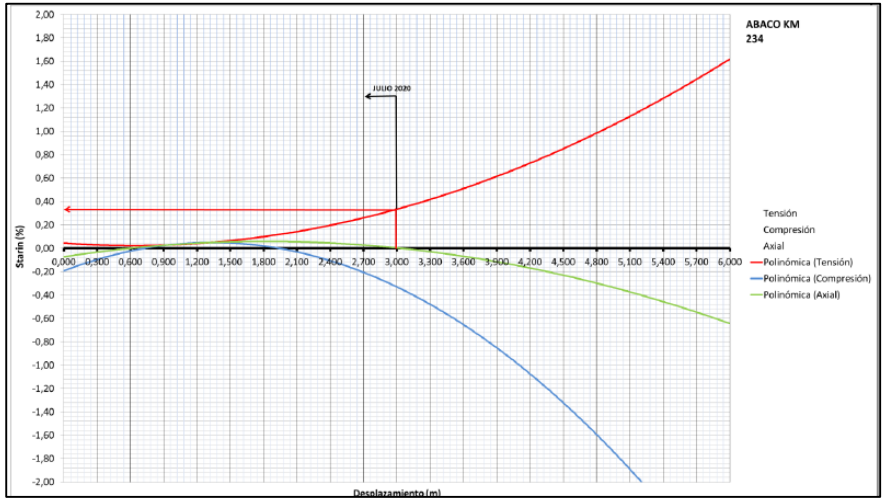
V&V



Sequence of solid ground displacement

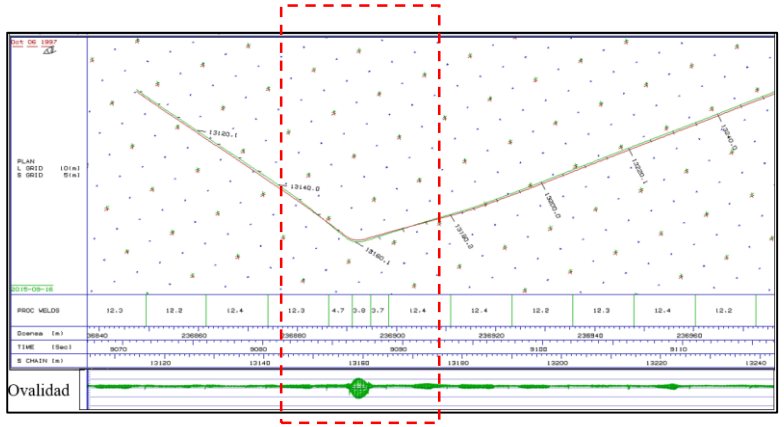


Maximum unit strain concentration (compressive) on the pipeline

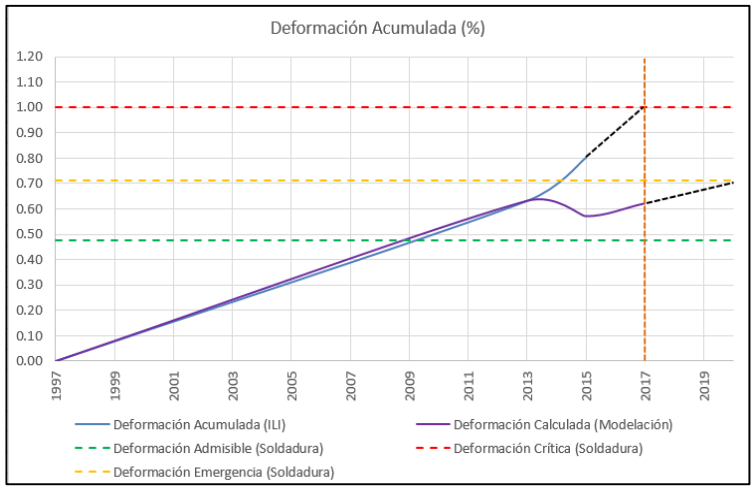


Soil-Piepe Interaction Abaqus

GENERAL CONTEXT OF APPLIED CASES: STRUCTURAL RESPONSE OF THE PIPELINE



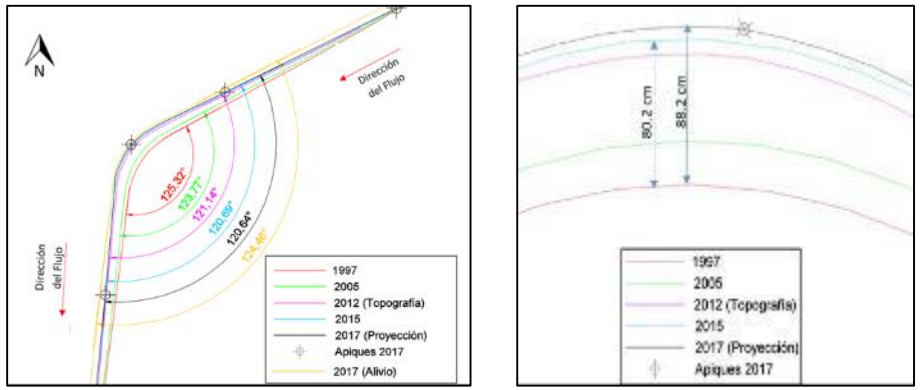
ILI Report 2015 (0,8%)



Annual strain increase rate (based on slope of strain behavior curve, based on ILI): 0.10%.

- 2014: 0.7%
- 2015: 0.8%
- 2016: 0.9%
- 2017: 1.0%

In the 3 years between 2014 and 2017, a unit strain increase of 0.3% is estimated.



Excavation for validation of pipeline position, induced curve, of 51° (i.e. 6D), closes and shifts to the right. An ovality in the induced curve is reported.

From the verification excavations executed in May 2017, it was found that the actual position of the pipeline matched the estimated displacement projection from the ILI 2015 report. Would the level of deformation also match?

GENERAL CONTEXT OF APPLIED CASES: STRUCTURAL RESPONSE OF THE PIPELINE

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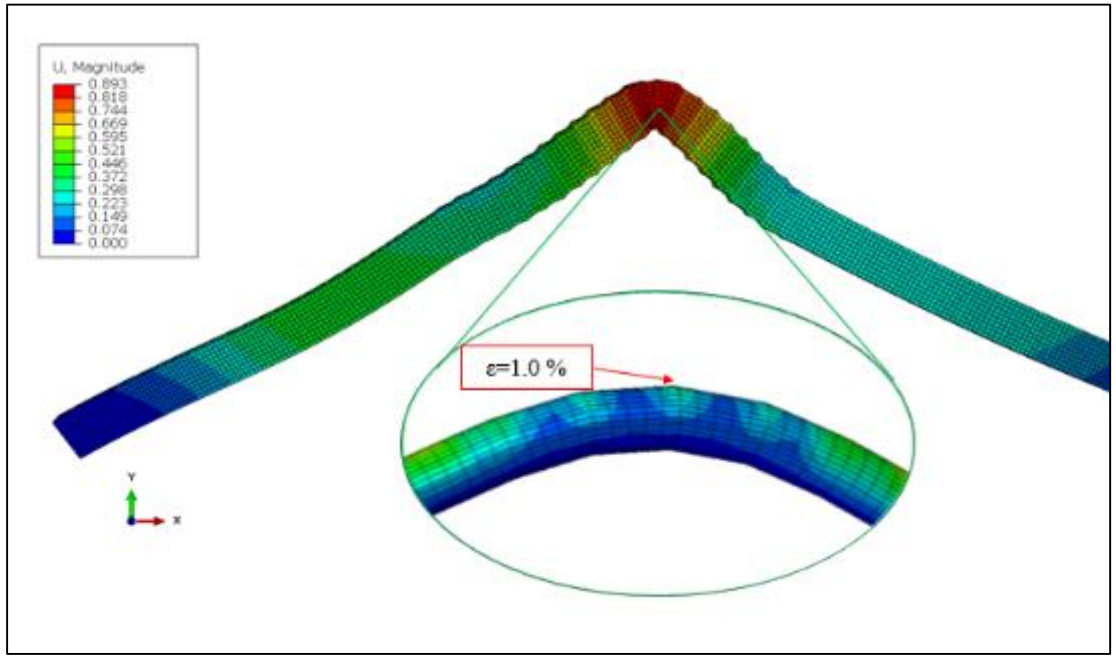
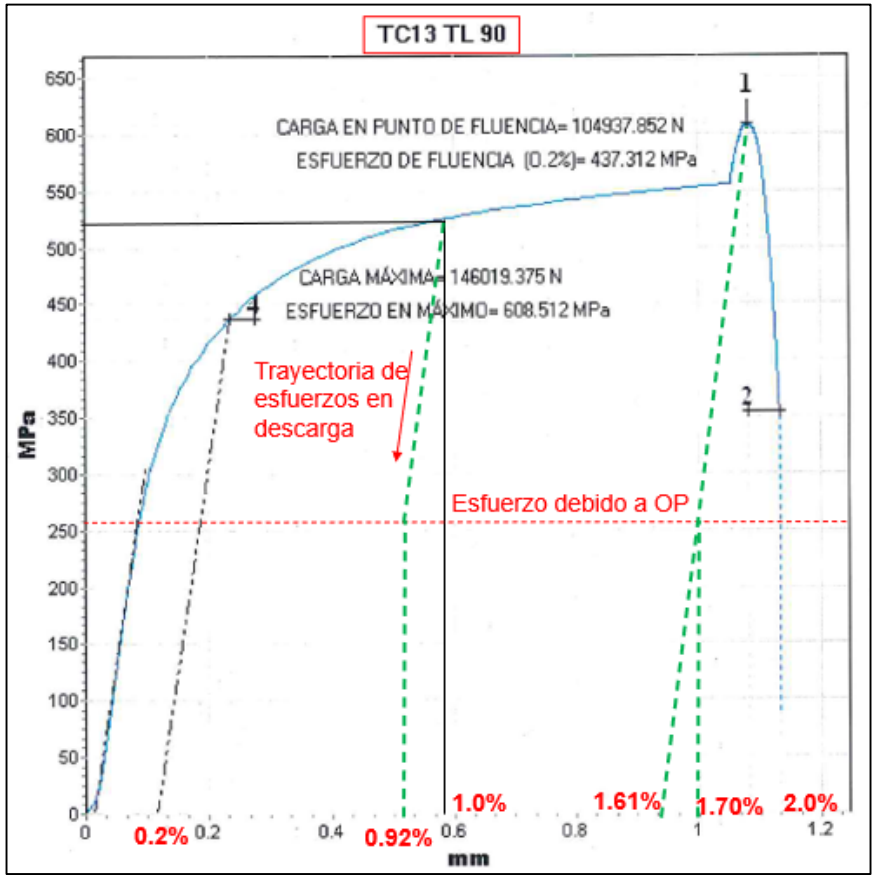


Numerical modeling: A maximum deformation of 1.0% was obtained, located in the inner part of the curve.

Stress relief.

GENERAL CONTEXT OF APPLIED CASES: STRUCTURAL RESPONSE OF THE PIPELINE



Stress-strain curve API 5L X70 steel

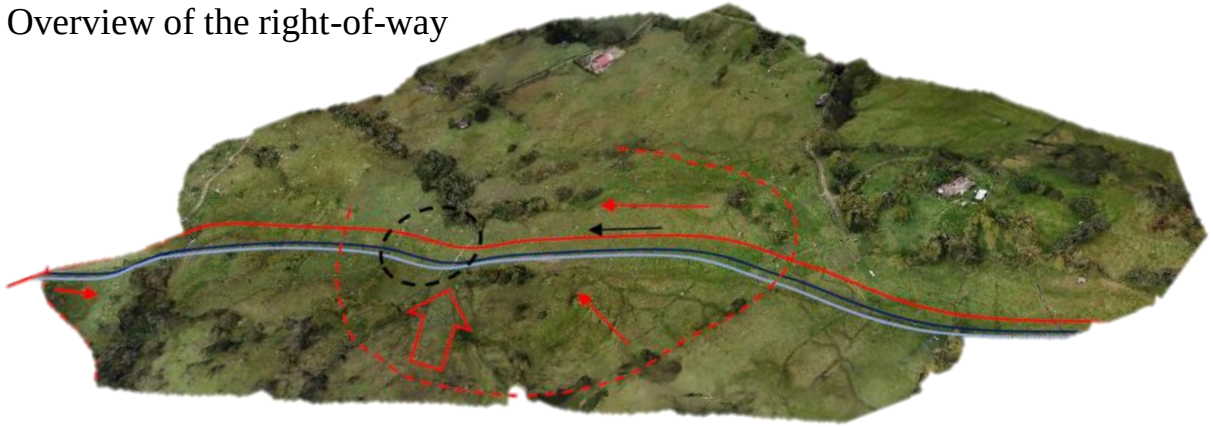
Cut.

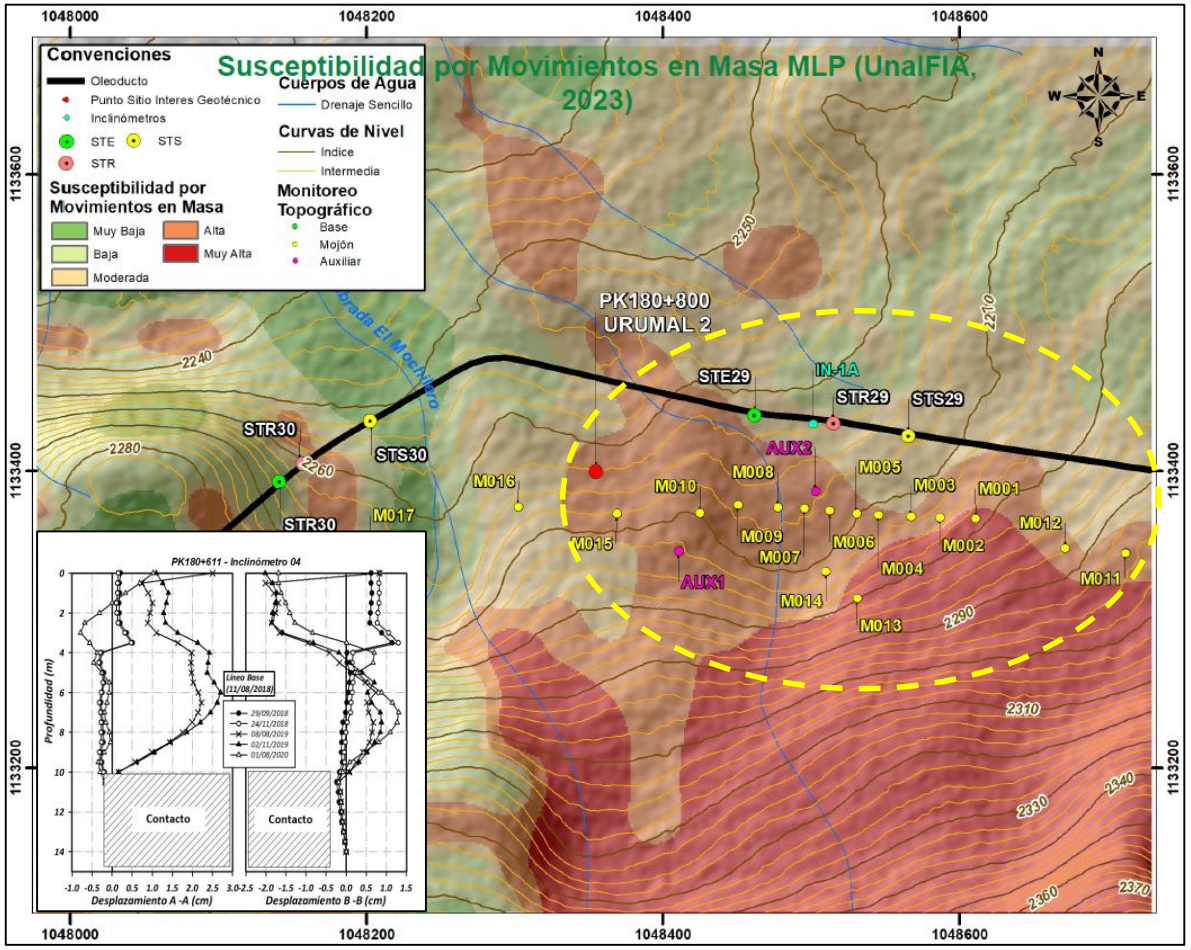
New alignment

What else can we do?
Pipe-Soil Interaction Abacus

CASE STUDY ONE

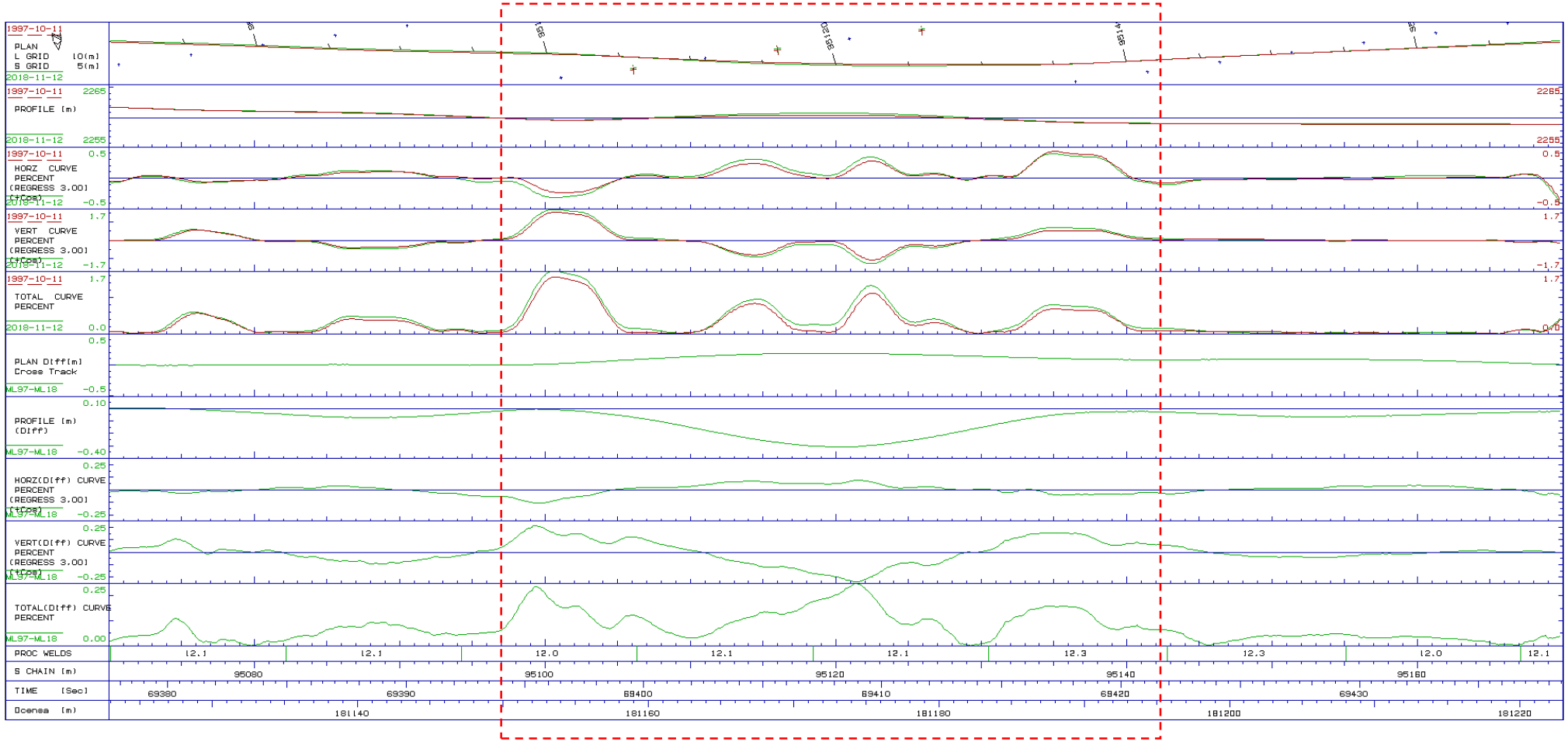
Overview of the right-of-way





Right-of-way monitoring

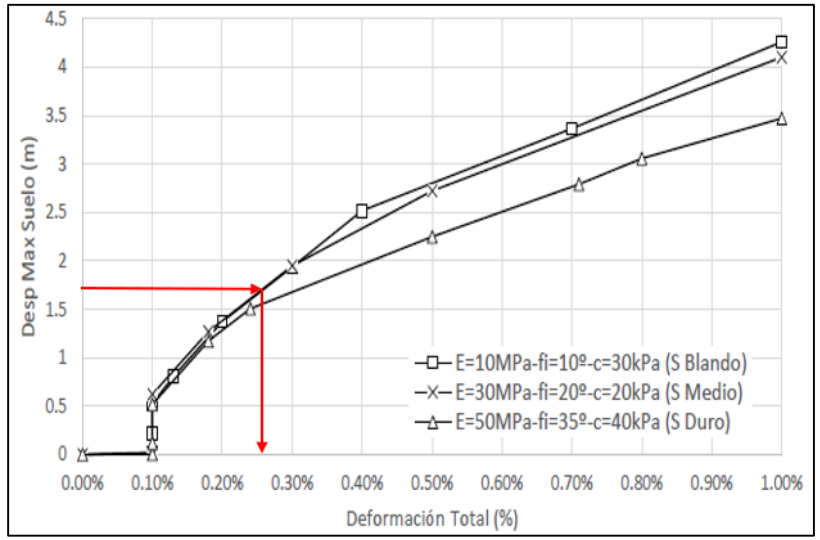
CASE STUDY ONE



ILI Report 2018 (0,24%)

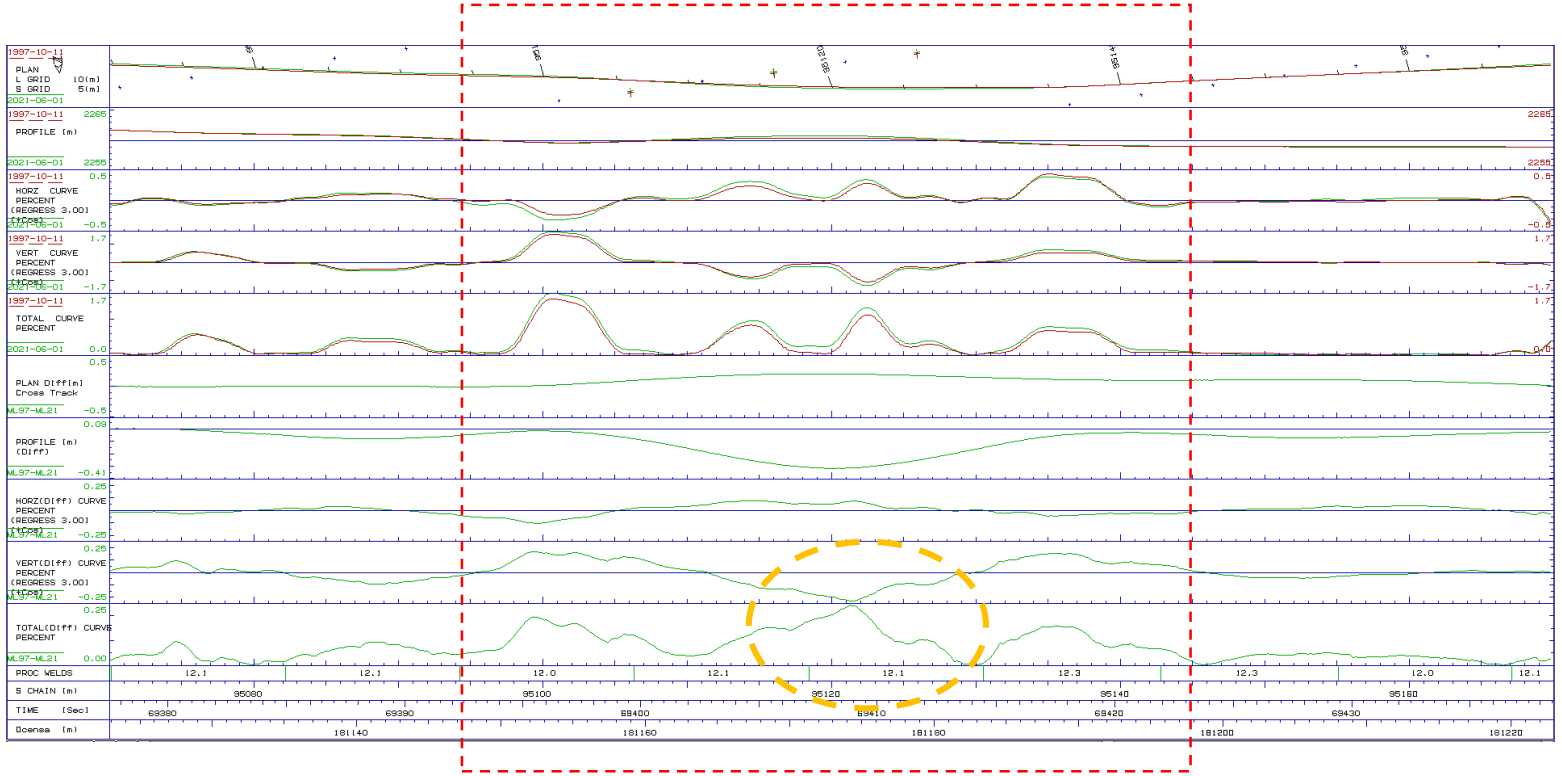
CASE STUDY ONE

What was the decision?



Not implementing risk mitigation measures

Confirming the decision

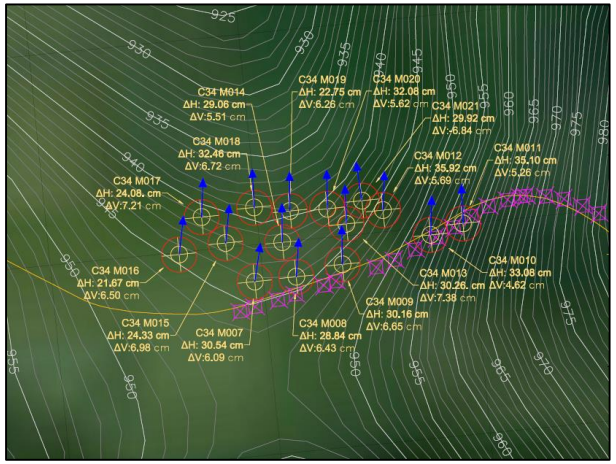


ILI Report 2018 (0,26%)

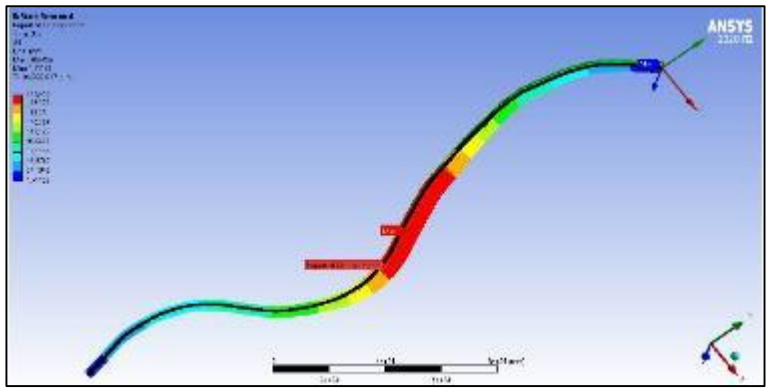
CASE STUDY TWO

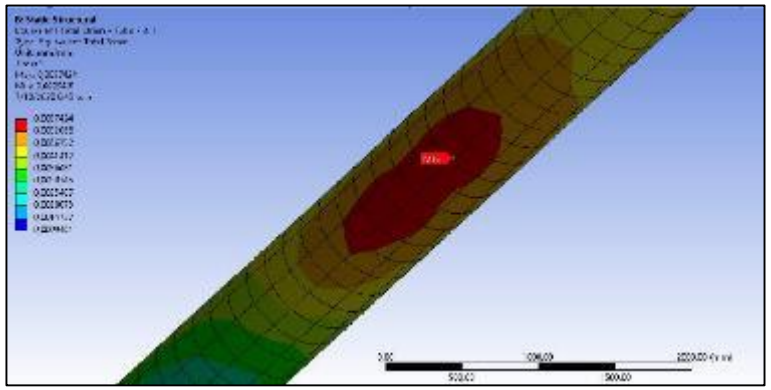
Panoramic of the right-of-way

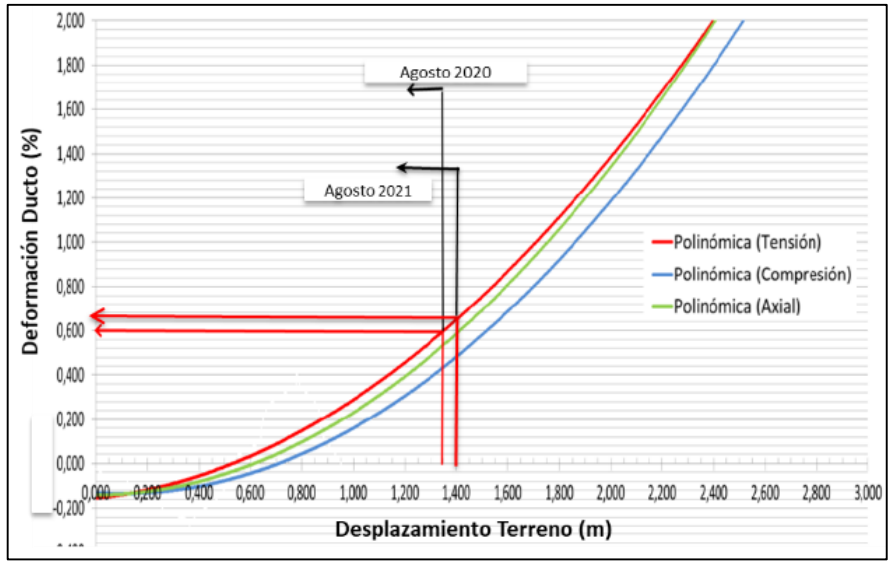
CASE STUDY TWO



Topographic monitoring

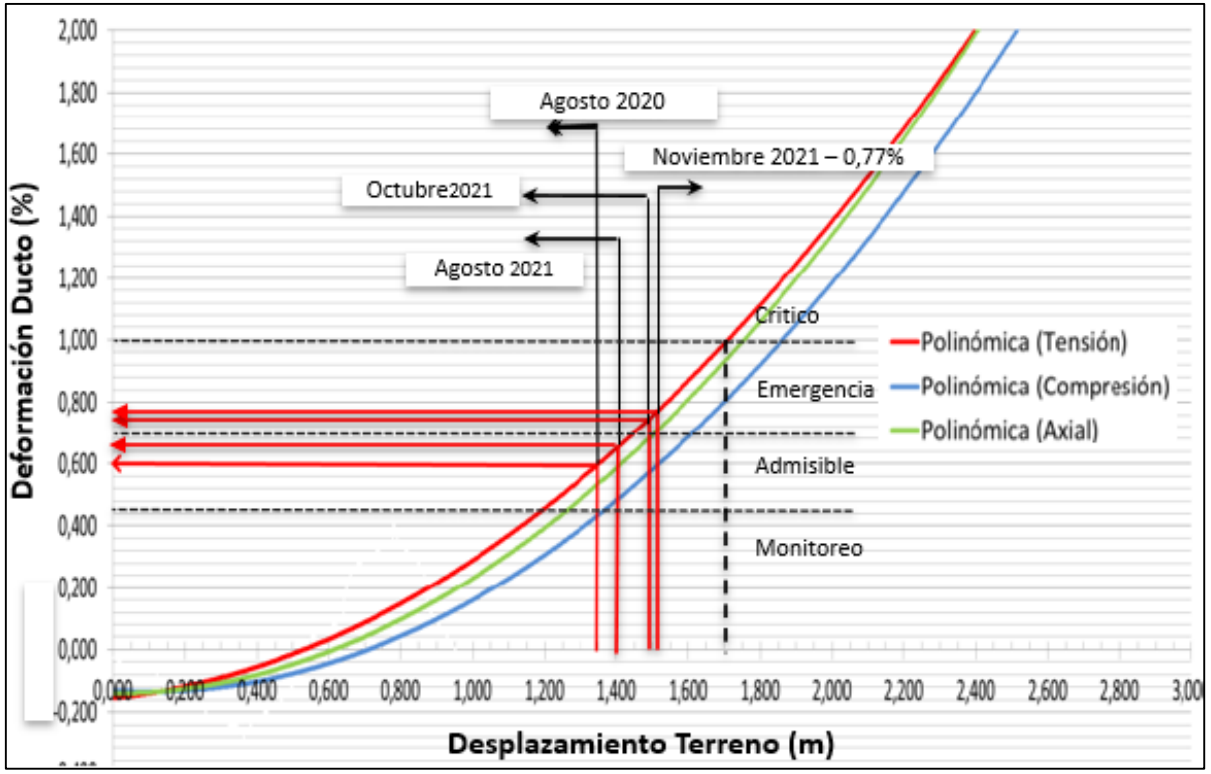



Numerical modeling (0,58%)



Soil-pipe interaction abacus (August 2021, 0,58%)

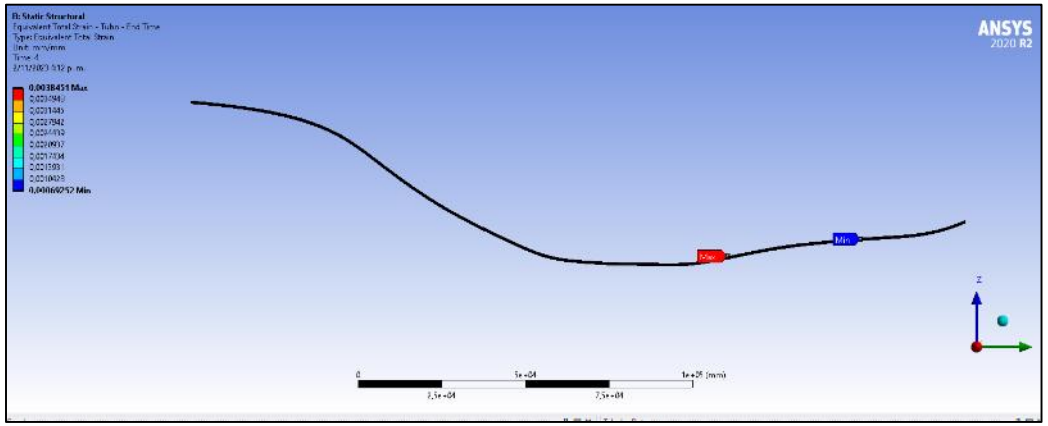
CASE STUDY TWO



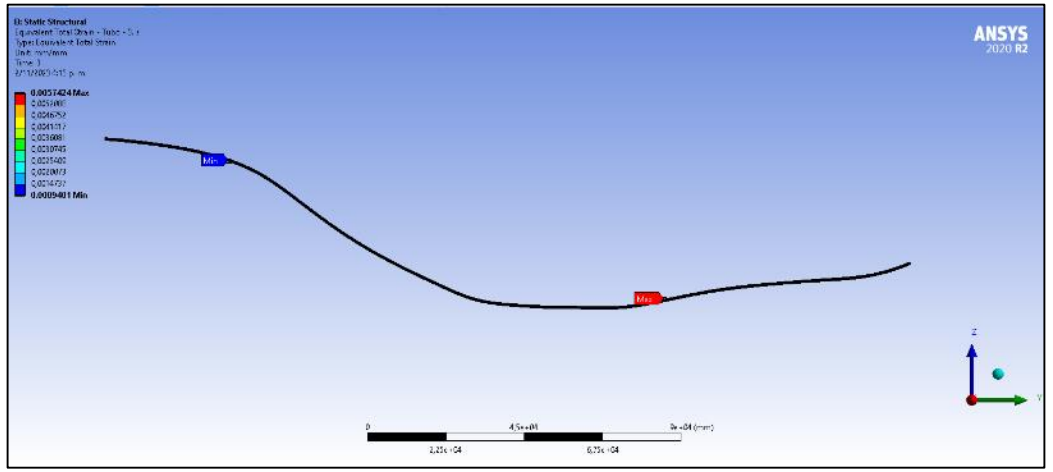
Soil-pipe interaction abacus (November 2021, 0,77%)

Stress relief, emergency (December 2021)

CASE STUDY TWO



Numerical modeling before stress relief (0,58%)



Numerical modeling after stress relief (0,38%)

CASE STUDY TWO

When should we return to stress relief???

QUESTIONS…