Τεχνικογεωλογική αξιολόγηση και διαχείριση κατολισθητικών φαινομένων κατά μήκος αγωγών φυσικού αερίου. Εμπειρίες από τον αγωγό TAP

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HDRRF 2020, Athens

3ο Επιστημονικό Forum για τη Μείωση της Διακινδύνευσης από Καταστροφές στην Ελλάδα
OUTLINE

I. General characteristics – Requirements

II. Landslide hazard and pipelines

III. Landslide Management Plan: Avoidance / Analysis / Mitigation

IV. Experiences from TAP pipeline

V. Discussion
I. GENERAL CHARACTERISTICS - REQUIREMENTS

- Steel tubes with inner diameter up to 1.2m. Most of them are buried in a 1-2m depth.
- Compressor Station: located along the line to move the product through the pipeline and retain the pressure.
- Block valve station: first line of protection for pipelines. Isolate any segment of the line for maintenance work or isolate a rupture or leak. Located every 50Km aprox.
A right-of-way (ROW) is a strip of land usually between 18 m and 36 m wide, containing one or more pipelines.

Access for inspection, maintenance, testing or in an emergency; Identifies an area where certain activities are prohibited to protect public safety and the integrity of the pipeline.

Activities such as paving, building permanent or temporary structures, and planting deep-rooted shrubs and trees are not allowed on the right-of-way.
I. GENERAL CHARACTERISTICS - REQUIREMENTS

Trench excavation

Trenchless techniques
Boring/jacking, auger bore, HDD (horizontal directional drilling) and micro-tunnelling
I. GENERAL CHARACTERISTICS - REQUIREMENTS

Morphology Challenges: Narrow ridges and Steep slopes

Lee, personal communication

PNG LNG

Lee, personal communication

PNG LNG

Lee, personal communication
II. GEOHAZARDS AND PIPELINES

- Landslides
- Liquefaction
- Active faults
- Karst

Landsliding is a major factor for pipeline route selection in mountainous regions.
II. LANDSLIDE HAZARD AND PIPELINES

A significant hazard for pipelines
- A significant operational risk
  - They can generate permanent ground displacement
    - tend to result in complete failure
    - significant leaks
    - major environmental impacts
    - long periods of service disruption
  - In mountainous areas: landslides the most common cause of pipeline rupture
  - !!!!! a buried pipeline must deform both axially and in bending to accommodate the movement (Nyman et al., 2008)

Trans-Ecuador Pipeline, from Petroecuador

- Destruction consequences in few Km range
- Very high cost/per day (!) service disruption
II. LANDSLIDE HAZARD ASSESSMENT

- Identify “hot spots” along the pipeline route:
  - International practice: Avoidance of landslide-prone areas is the hazard reducing option both in terms of cost and time saving

- Investigation and stabilisation is not the best international practice due to time and cost constraints (Sweeney, 2005)

- When re-routing is not possible: Prioritise risk reduction measures after detailed evaluation of all site conditions

- An important factor for the finalisation of the route
II. LANDSLIDE HAZARD ASSESSMENT

- **First-time failures**: characterised by large, rapid displacements
  - high velocity, large events to slowly developing very small, shallow features
- **Reactivation of pre-existing landslides**: movements, along pre-existing shear surfaces, (can include expansion)
  - occurs more frequently than the generation of new landslides

*Pre-existing landslide on the flank of a ridge, where a pipeline route runs*

Triggers can be anything from major earthquakes, rainfall or the effects of man.
II. LANDSLIDE HAZARD ASSESSMENT

Event reaches the RoW influenced by:

- Nature and size of the landslide event (controlled by the site geology and geomorphology)
- Proximity to the pipeline
- Position of the pipeline relative to the landslide

Credible initiating event:

1. Increased pore-pressures (heavy rainfall or snow melt)
2. Seismic ground shaking
3. Removal of support by erosion of the landslide or slope toe
4. Loading the head of the landslide or slope
II. LANDSLIDE HAZARD ASSESSMENT

- Landslide hazard varies with the terrain setting.
- Ridge crests best international practice
- But ridge crest alignments are not risk free.

(M. Lee, personal communication)
POSSIBLE FAILURE EVENT SCENARIOS ASSOCIATED WITH PIPELINE RUPTURE

Zone 1: Large and active landslides, can reach the mountain crest (upslope or lateral retrogression of the main landslide head) and can impose threat to the pipeline integrity.

Surface water ponds and small lakes in the middle of the slope.

The international best practice, is to identify landslide features and avoid by routing along ridge crests and spurs, and minimizing the exposure to potentially unstable, steep side slopes.

Not all landslide events that reach the pipeline will cause rupture. Some may only lead to exposure or the damage may be limited to bending or buckling.

When all the hazard landslides are not avoided, they must be feasibly constructed, with reasonable risk or reasonable engineering remedial measures.

Unforeseen landslide problems could still arise during the construction of a pipeline project.

Pipeline rupture as a result of removal of support along a significant length (e.g. greater than 30m), due to retreat of the landslide main scarp (upslope retrogression), failure of the landslide flanks (lateral expansion).

Zone 2: Reactivation along pre-existing shear surfaces. In a dynamic geomorphological terrain, the route may pass in close proximity to known landslides on the ridge flanks and slopes that are believed to have the potential to fail at some point in the future, either under static (increased pore-pressures and ground removal) and/or dynamic conditions (seismic ground shaking) due to moderate to strong earthquake events.

Zone 3: Hazard resulted from the burial by landslide debris.

Whether the "expected" landslide event reaches the RoW and impacts the pipeline is influenced by the nature and size of the expected landslide event (controlled by the site geology and geomorphology), the proximity of the existing landslide feature to the pipeline and the position of the pipeline relative to the landslide (i.e. upslope, beyond the lateral margin, crossing or downslope of the toe).
II. LANDSLIDE HAZARD ASSESSMENT

Hazard rating according to the engineering geological judgment:

- **None**: No hazard
- **Negligible**: Slide can happen under extreme circumstances
- **Low**: Slide is impossible to happen during the project life
- **Medium**: Sliding can happen during the project life
- **High**: Sliding is expected to happen during the project life

Hazard classes relative to landslide body and proximity to pipeline (M. Lee 2013)
Identify "hotspots" along the route

Create criteria - Classify landslides based on:
- Distance from the pipeline
- Relevant location
- Landslide Activity
- Sliding depth
- Mechanism of failure
- Triggering factor
# LANDSLIDE INVENTORIES

## LANDSLIDE EVALUATION SHEET

<table>
<thead>
<tr>
<th>Identification code</th>
<th>Location</th>
<th>Relative position to pipeline</th>
<th>Geological setting</th>
<th>Terrain</th>
<th>Surface water</th>
<th>Evidence of sliding</th>
<th>Landslide type</th>
<th>Secondary slides on landslide body</th>
<th>Landslide area</th>
<th>Landslide max length</th>
<th>Landslide max breadth</th>
<th>Monitoring evidence</th>
<th>Slide surface depth</th>
<th>Risk assessment</th>
<th>Notes - Actions suggested</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALS-608</td>
<td>108+800</td>
<td>Above the pipeline. 12m from the toe.</td>
<td>Weathered and folded flysch rock mass and in superficial soil materials of significant thickness, various origin and variable engineering geological behaviour, namely a) river deposits, b) alluvial deposits, c) landslide materials, d) terrace deposits and e) scree of flysch origin</td>
<td>Moderately steep on the south side of the pipe.</td>
<td>None on the landslide mass. River adjacent.</td>
<td>Old back-scarp. River bed erosion of fresh material.</td>
<td>Rotational. Deep.</td>
<td>Yes.</td>
<td>53689 m²</td>
<td>465 m</td>
<td>Three inclinometers. Inconclusive readings.</td>
<td>Deep</td>
<td>estimated</td>
<td>measured at monitoring point</td>
<td>found (borehole data)</td>
</tr>
</tbody>
</table>
International oil and gas pipelines: geohazard related decision making is risk-based and not driven by Codes.

Challenge is to estimate risk and communicate it to higher management

Lee, Personal communication
III. Landslide Management: Avoidance / Analysis / Mitigation

AVOIDANCE
- LANDSLIDE RECOGNITION
  - RE-ROUTING

MITIGATION
- INVESTIGATION, NUMERICAL MODELLING
  - DESIGN AND CONSTRUCTION

STABILIZATION
- INVESTIGATION, NUMERICAL MODELLING
  - DESIGN AND CONSTRUCTION

MONITOR
- DEFINE SET BACK LIMITS
  - OPERATIONAL MONITORING

M. Lee, personal communication
IV. Experiences from TAP pipeline – The Albanian mountain section

The Trans Adriatic Pipeline (TAP) route. The study area (shown with a black rectangle) spans approximately from 70km to 136km (KP70-KP136)
THE ALBANIAN MOUNTAINS: LANDSLIDE CAUSES

PGA 0.4g; 10% chance of exceedance in 50 years (1 in 475 year return period)

Average annual rainfall probably 1500-2000mm

Probably the most challenging onshore section of the SCPX-TANAP-TAP pipeline system: Combination of weak rocks, steep slopes, rainfall and snow melt and strong ground accelerations (earthquakes) creates an environment prone to landsliding.

At a regional level, variations in rock condition play a key role in determining where landslides have occurred.
THE WORK WAS EXECUTED MOSTLY ON THE RIDGE ALONG THE PIPELINE ROUTE

Indicative TAP RoW (dashed line) along steep and narrow terrain in central Albania
Desk Study

- Identification from the topographic map - Sudden changes of slope angle, flat areas or bulge on slopes (square, vis-à-vis contour lines).
- Identification from satellite images – bare with no vegetation and/or steep slopes.
- Identification of surface water ponds and lakes on the slope.
Tension cracks on the ridge crest – potential for landsliding to affect the RoW.

Opening at the top and parallel to the ridge indicating movement.

Deformed vegetation due to landsliding.

Small lakes in the middle of the slope.

Irregular topography with small hills and back-tilts along the slope.
ENGINEERING GEOLOGICAL EVALUATION FOR EVERY GEOHAZARD AREA

- Qualitative characteristics about the quality of the rock mass (lithology, rock mass structure, weathering, strength, joint characteristics, water presence)
- Measurements of key structural elements
- Geotechnical classification with the GSI system
- Estimation of the weathering profile
ROCK MASS CLASSIFICATION

GSI CHART FOR HETEROGENEOUS ROCK MASS LIKE FOR FLYSCH

<table>
<thead>
<tr>
<th>STRUCTURE AND COMPOSITION</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>TYPE I</td>
<td>Undisturbed, with thick to medium thickness sandstone beds with sporadic thin films of siltstone. In shallow tunnels or slopes where confinement is poor, the mode of failure has a kinematic character controlled by the bedding planes and GSI is meaningless.</td>
</tr>
<tr>
<td>TYPE II</td>
<td>Undisturbed massive siltstone (stratification planes are imperceptible) with sporadic thin interlayers of sandstones</td>
</tr>
<tr>
<td>TYPE III</td>
<td>Moderately disturbed sandstones with thin films of interlayers of siltstone</td>
</tr>
<tr>
<td>TYPE IV</td>
<td>Moderately disturbed rockmass with sandstone and siltstone similar amounts</td>
</tr>
<tr>
<td>TYPE V</td>
<td>Moderately disturbed siltstones with sandstone and sandstone interlayers. The structure is retained and deformation - shearing is not strong</td>
</tr>
<tr>
<td>TYPE VI</td>
<td>Moderately disturbed siltstones with sparse sandstone interlayers</td>
</tr>
<tr>
<td>TYPE VII</td>
<td>Strongly disturbed, folded rockmass that retains its structure, with sandstone and siltstone in similar extend</td>
</tr>
<tr>
<td>TYPE VIII</td>
<td>Strongly disturbed, folded rockmass, with siltstones and sandstone interlayers</td>
</tr>
<tr>
<td>TYPE IX</td>
<td>Desintegrated rockmass that can be found in wide zones of faults or/and of high weathering. In this type, mainly brittle material is present with some disturbed siltstones between rock pieces</td>
</tr>
<tr>
<td>TYPE X</td>
<td>Tectonically deformed intensively folded/faulted siltstone or clayey shale with broken and deformed sandstone layers forming an almost chaotic structure</td>
</tr>
</tbody>
</table>

Marinos 2007, 2017
ZONATION OF THE ROCK MASS QUALITY ALONG THE ROUTE

Typical examples of flysch type VIII (left) and flysch type IX (right) at landslide masses.
Inventory of 82 landslides compiled from satellite imagery and field survey. Landslides are depicted by polygons.
SEVERAL LARGE LANDSLIDES – SOME ACTIVE WITH FRESH CRACKS –
THE MOST HAZARDOUS AREA: 75KM-90KM
Landslide inventory of the TAP segment between 72km and 79km, where several landslides are located close to the TAP RoW, threatening pipeline integrity
LANDSLIDE S-AL-N23
KM: 81
ONE SLIDE IS OFTEN TRIGGERED BY OTHER SLIDES AT THE BOTTOM OF THE MOUNTAIN
Boreholes have been drilled.

Weather and access constraints.

Key findings:

- Landslides are typically deep-seated (>20m to base)
- Multiple shear surfaces likely to be present
A RIDGE WHERE TWO LANDSLIDES ARE MET

Pipeline axis
GEOHAZARD: N40

Pipeline axis
GEOHAZARD: N40
GEOHAZARD: N40 BH-3
GEOHAZARD: N40 BH3
Inclinometer BH-8B

- Sliding surface at 47 m depth
- Horizontal movement of 16 mm from January 2015
- The horizontal movement was measured between the end of January until mid-March 2015
- Northwest direction of displacement
- Between the two last measurements movement of 5 mm
HAZARD CLASS (TAP AD HOC)

Based on:
- landslide area
- landslide depth
- proximity to pipeline
- landslide activity
- ground quality
- slope angle

- Parameters affecting expected damage to pipeline if landslide is activated (Potential impact on the pipeline upon activation)

- Parameters affecting possibility of landslide activation (likelihood of activation)

- Tension cracks along a ridge flank, indicating potential for upslope retrogression of pre-existing landslides

- Very steep landslide back scar extending to the ridge crest, with potential for further upslope retrogression
EVENT TREE ILLUSTRATING THE SEQUENCES OF EVENTS INVOLVED IN GENERATING PIPELINE RUPTURE
THE LANDSLIDE RISK MODEL DEVELOPED

1. COULD A CREDIBLE EVENT REACH THE PIPELINE?
   - Yes
   - No

2. CAN THE EXPECTED LANDSLIDE CAUSE PIPELINE RUPTURE EVENT?
   - Yes
   - No

3. COULD THE EVENT OCCUR UNDER STATIC CONDITIONS?
   - Yes
   - No

4. COULD THE EVENT OCCUR UNDER SEISMIC CONDITIONS?
   - Yes
   - No

Risk Levels:
- NEGLIGIBLE TO NO RISK
- LOW RISK
- MEDIUM RISK
- HIGH RISK
LANDSLIDE RISK ASSESSMENT

Landslide risk assessment results for the pipeline route from approximately 73km to 80km (area north of Panarit village).
LANDSLIDE MANAGEMENT PLAN: AVOIDANCE

Areas requiring re-routes:

- minor route changes (blue boxes)
- significant deviations from the current route are expected (purple box).

All re-routes to be verified in the field for landslide and constructability issues.
LANDSLIDE MANAGEMENT PLAN: MITIGATION

Key areas where mitigation is anticipated

Use of retaining structures and geotechnical measures along long sections of RoW

Unprecedented in the SCPX-TANAP pipeline system (typically piling is done for short sections of 50-100+m) (Lee, Pers. Com)

Identify “hotspots”, investigate (mapping and boreholes), followed by conceptual design of mitigation measures.
Mitigation measures to ensure that the RoW is isolated from any landslide activity on the ridge flanks.
V. DISCUSSION

Crucial questions to the geohazard expert:

- Could a credible event breach the ridge?
- Could a credible landslide reach the pipeline?
- Do we expect minor or large permanent ground displacement (e.g. \(<1\)m or \(>1\)m)?
- If the landslide reaches the pipeline:
  - Event width \(<\) pipeline spanning failure criteria?
  - Event width \(>\)pipeline spanning failure criteria?
- Could the expected landslide cause pipeline rupture?
  - Could the event occur under static conditions
  - Could the event occur under seismic conditions

Most of the problems arise from the tight schedules that do not allow this whole assessment.
Acknowledgements

Work funded by E.ON Technologies GmbH (currently Uniper GmbH) S.A.