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論文題目	Assessing Pipeline Failure Probabilities and Hotspots at Multiple Spatial Scales：The Development of a Novel Integrated Methodology to Simulate the Cascading Impacts of Debris Flows on Oil Pipelines （複数の空間スケールにおけるパイプラインの破損確率とホットスポットの評価：土石流が石油パイプラインに与える連鎖的な影響を計算するための新しい総合的方法の開発）		

（論文内容の要旨）

Landslides represent the number one natural hazard impacting oil and gas transmission pipelines leading to explosions, fires and oil in Europe and the United States (U.S.), and often result in huge economic losses and impacts to communities. In particular, rainfall induced debris flows, a type of landslide, are of concern due to increased precipitation patterns brought about by climate change. These natural hazard triggered chemical accidents are known as Natech accidents. At a regional scale, there are no available methodologies to assess aboveground transmission pipeline failure hotspots due to the impact of rainfall-induced debris flows. Moreover, there are only limited efforts to assess the probability of chemical accidents along oil and gas transmission pipelines triggered by landslide.

The aim of this study is to develop a novel methodology to simulate the cascade chain of events from the triggering of the debris flow, to its propagation, and the impact of the debris flow on transmission pipeline in order to investigate and assess pipeline hotspots and failure probabilities at different spatial scales and for various pipeline arrangements. In order to fulfil the study aim, the study proposed the following objectives:

- To develop a methodology to identify pipeline hotspots at a regional scale due to rainfall-induced debris flows;
- To further develop the methodology to assess pipeline failure probabilities at the regional scale due to rainfall-induced debris flows considering the uncertainty of soil properties and pipeline operation conditions; and
- To investigate different pipeline arrangement scenarios and assess the corresponding pipeline failure probabilities in the near-field.

To achieve the aim and goals, the study first proposes a methodology to simulate the three phases of the debris flow that include the triggering of the debris flow, its propagation, and the impact of the debris flow on the pipeline at a regional scale. To conduct the simulation, the study uses the Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability Analysis Model (TRIGRS), coupled with the Rapid Mass Movement Simulation (RAMMS) tool, and a pipeline failure mechanical model. The proposed methodology was validated and calibrated using historical data from a rain-induced debris flow event that occurred in Mocoa city, Colombia, in 2017, showing promising results.

Furthermore, the study proposes a methodology to assess the pipeline failure probability at the regional scale considering the uncertainty of soil properties and pipeline operating conditions. The methodology uses the Green-Ampt and slope stability model with the consideration of soil parameters (cohesions and internal friction angle) uncertainty. These parameters can be defined as probability density functions, and by means of Monte Carlos simulations to random sample the values, the debris flow occurance probabilities in each cell of the spatial grids are estimated. Given the large area to be simulated, a methodology is prosed to integrate the cells of the grid in order to reduce computational time. Specifically, the cells having the same probability values are integrated, and the spatial grid is separated into probability intervals. These intervals are used as the input for the debris flow simulation and the loads of the debris flow can be calculated. The loads are then used as one of the input into a modified pipeline failure mechanical model that allows the consideration of the effects of the pipeline operating conditions. Given the uncertainty in pipeline operating conditions (internal pressure and temperature), the operating conditions are also defined as probability density functions. A Monte Carlo simulation is used to conduct random sampling of the operating conditions values and the pipeline failure probability of each segment can be obtained. Thus, the loads can be estimated with the combination of different probability intervals, which are used to calculate the pipeline Natech accident probability.

The above approaches are proposed for the analysis of debris flow impacts on pipelines at the regional scale. Nonetheless, local authorities, stakeholders, and operators often need to consider the pipeline alignment in the near-field when these traverse debris flow-prone areas during the pipeline life cycle. However, there is limited research that considers the pipeline layout, alignment, segment lengths (length of pipeline between rigid supports or other structures), and uncertainty of operating conditions simultaneously in the near-field. Thus, the study proposes a methodology to model the process of debris flow and the impact on the pipeline through the integration of 3D debris flow simulation (DebrisInterMixing) and modified pipeline failure mechanical models. Then, by introducing a polar coordinates approach, the pipeline failure probability can be obtained under different pipeline alignments, segment lengths, and operating conditions. The results show that with the increase in pipeline segment length, the pipeline failure probability increases. The results can also be mapped to show the pipeline failure probability for different pipeline layouts.

This study developed a novel quantitative-mechanistic methodology to simulate the cascade process from the rainfall infiltration in areas subject to debris flow, to the debris flow process, the impact of debris flow loads on oil and gas transmission pipelines, to the estimation of pipeline failure probabilities at both the regional scale and in the near-field. In this sense, the study provides a valuable tool, that is computationally efficient, to support decision-making processes. In particular, the study can support the decisions of local authorities, stakeholders, and operators for risk assessment, prioritization of hazard mitigation measures and emergency planning, or decisions regarding pipeline siting. Finally, this research provides basic knowledge and information needed for Natech risk assessment and management of aboveground transmission pipelines subject to debris flows.