E105

Evaluation of Rain-induced Debris Flow Impacts on Pipelines. (Natech Accident)

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Introduction

Global climate changes may significantly influence temperatures and precipitation patterns, increasing the frequency of severe meteorological events such as heavy rain. Prolonged heavy rain may dramatically lead to the occurrence of debris flow (Shallow landslide), which can cause damage to people, property and the environment. (1) In some cases, oil and gas transportation pipelines, which traverse long distances, are exposed, and can be damaged causing the release of hazardous materials. These accident scenarios are called natural hazard triggered technological accidents (known as Natechs).(2) In a previous study(3) a simplified quantitative-mechanistic model was proposed to estimate the probability of landslides and the probability of failure of the pipeline due to landslides. In their study, the authors used a simplistic slope stability analysis method to determine the stability of each node from the provided Digital Elevation Model (DEM), and then estimated the subsequent strains on the pipeline due to the landslide in the far-field. However, the model did not consider landslide dynamic processes. The aim of the current study is to develop a mechanical model which allows the evaluation of rain-induced debris flow impacts on pipelines considering landslide dynamic processes. In this study, a slope stability model combined with a Green-Ampt infiltration model(4), and the DEBRIS FLOW module of RAMMS(5), are used to simulate the dynamic process of debris flow. Through a pipeline failure model, the pipeline response to the debris flow can be known. The methodology can show the cascade process of the disaster chain from the initial heavy rainfall to the pipeline damage. The methodology of the will be presented in the next section.

Methodology

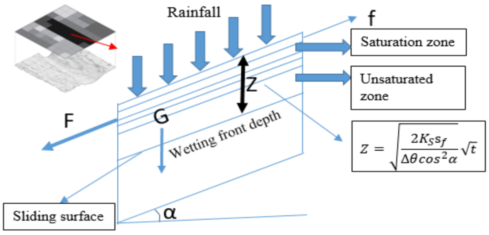

Figure 1

$$I = \Delta\theta Z cos\alpha$$
$$N = Gsin\alpha$$
$$f = Ntan\varphi + c\Delta L/cos\alpha$$
$$F = Z\Delta L\gamma_w sin\alpha + Gsin\alpha$$

When $F > f$, the block is unstable.

I: The amount of infiltration
$\Delta\theta$: The difference between saturated moisture content and natural moisture content
G: Total gravity
c: Viscosity
α: Slope angle
φ: Internal friction angle
γ_w: Unit weight
K_S: Saturated permeability coefficient
S_f: soil water suction

(1) The model of slope stability under rainfall.

The spatial analysis of the model is carried out using an ArcGIS platform, and grid data. Each cell and the elevation of the position of the cell are combined into a unit block. A unit block is a debris flow unit. Each block is analyzed to determine the source of the debris flow through the developed slope stability model. As shown in Fig 1, the wetting front depth, *Z*, can be calculated, and the plane of the wet front is considered as the sliding surface. Thus, as shown in the equation listed, the relationship of the duration of rain (t) and the critical slope degree can be derived. For the specific rain duration, when the slope of the block exceeds the critical slope angle, it can be regarded as the source of debris flow.

(2) The Debris flow simulation.

The step is conducted in the two-dimensional dynamics modeling RAMMS (rapid mass movements simulation) software. Through the spatial analysis, for the specific duration of rain, the cells larger than the critical slope angle can be extracted in ArcGIS and used as the input into RAMMS. The input of the simulation also includes the density (ρ) and depth of the wetting front (Z) of the debris flow source. However, in the simulation, there are other two main parameters μ (friction coefficient) and ξ (turbulence coefficient), which need to be calibrated by conducting the experiment or the back-calculation. After obtaining the parameters (ρ, Z, μ, ξ), as shown in Fig 2, the variation of velocity, height, and the impact range of debris flow with time can be calculated. The output can be used as the input for the pipeline failure model.

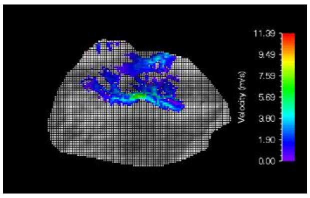

Figure 2

(3) Pipeline failure model.

Because of the pipeline structural features, it can be represented as a beam structure as shown in Fig 3. Due to the impact of debris flow on the pipeline, the stress state of the pipeline will be changed into a different state as shown in Fig 4. The impact (joint load) of the debris flow on the pipeline leads to bending moment and the tensile stress located at the boundary of the impact on the pipeline, as shown in Fig3. The tensile stress can be calculated with the joint load by bending moment and the tensile stress equations. Then based on the conservative estimation and first strength theory, as shown in Fig 5, that the tensile stress exceeds the yield strength (Critical strength) of the pipeline is set as the failure criterion. Thus, for the special duration of rain, the pipeline failure can be determined by comparing the tensile stress with the yield strength.

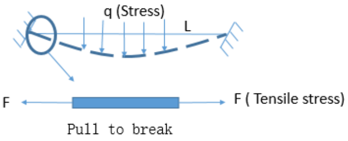

Figure 3

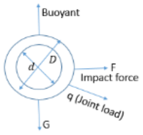

Figure 4

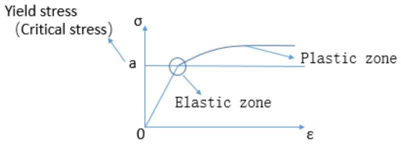

Figure 5

Bending moment $M = qL^2/12$

Tensile stress $F_T = \frac{My}{I}$ $y = D/2$

$\mathrm{I} = \pi D^2(1 - \partial^4)/64$

$\partial = d/D$

Assumption:

(1) Do not consider the underground water.

(2) Do not consider the vegetation and land use.

(3) Rainfall intensity is greater than saturated permeability coefficient.

(4) The sliding surface is located at the depth of wetting front.

(5) In the model, before the rain stop, even if the block is unstable, the debris flow will not occur.

Reference:

(1) Girgin, Serkan. 2017. "Analysis of Pipeline Accidents Induced by Natural Hazards.".

(2) Krausmann, E., A.M. Cruz and E. Salzano, Natech Risk Assessment and Management– Reducing the Risk of Natural-hazard Impact on Hazardous Installations, *Elsevier* (2017).

(3) Alvarado-Franco, Juan Pablo, David Castro, Nicolas Estrada, Bernardo Caicedo, Mauricio Sánchez-Silva, Luis A. Camacho, and Felipe Muñoz. 2017. "Quantitative-Mechanistic Model for Assessing Landslide Probability and Pipeline FailureProbability Due to Landslides." *Engineering Geology* 222(April):212–24.

(4) CHANG Jin-yuan，BAO Han，WU Fa-quan，CHANG Zhong-hua，LUO Hao. 2015. " Discussion on stability of shallow landslide under rainfall" *Rock and Soil Mechanics* 36(April):4

(5) Gan, Jianjun, and Y. X. Zhang. 2019. "Numerical Simulation of Debris Flow Runout Using RAMMs: A Case Study of Luzhuang Gully in China." *CMES - Computer Modeling in Engineering and Sciences* 121(3):981–100.