

Research on Deformation Characteristics of Pipelines Under Landslide Action

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Abstract: Landslide disasters often occur along oil and gas pipelines, seriously affecting the safety of oil and gas transportation. Therefore, it is urgent to study the deformation and damage characteristics of pipelines under landslide disaster conditions. This article takes oil and gas pipelines under landslide disaster conditions as the research object, and based on numerical simulation methods, focuses on the influence of different landslide parameters on pipeline deformation and damage. The research results indicate that the length, width, height, and slope of landslides, as well as the relative position of pipeline landslides, have a significant impact on pipeline deformation and damage; When the oil and gas pipeline is laid in the middle of the landslide, the response of pipeline deformation and failure to slope sliding is most significant; The prediction results of the pipeline landslide geological hazard warning model are highly consistent with the original data and have wide applicability. The research results are of great significance for monitoring and evaluating geological hazards of pipeline landslides, and reducing the risk of geological hazards of pipeline landslides in the monitoring area.

Keywords: Geological hazards of pipeline landslides, Numerical simulation.

1. Introduction

Landslide geological hazards are an important reason for the inability of gas pipelines in landslide prone areas to operate normally. On September 12, 2012, a landslide occurred in Luzhou City, Sichuan Province, causing the main natural gas pipeline to be smashed and nearly 2000 cubic meters of natural gas to leak, posing a huge threat to the safety of residents' lives and property. Local residents were forced to evacuate urgently; On July 2, 2016, a Sinopec oil pipeline in Nan'an District, Chongqing was pulled apart by a landslide, resulting in a diesel leak and some flowing into the Yangtze River, causing serious environmental pollution; On July 2, 2017, the slope of a highway in Qinglong County, Qiannan Prefecture, Guizhou Province collapsed and slid, resulting in the rupture of a gas pipeline laid along the slope. This led to a natural gas leak and caused a combustion explosion, resulting in 8 deaths and 35 injuries. Therefore, how to scientifically determine the deformation and failure mechanism of gas pipelines under landslide disasters; Establishing a precise warning model for pipeline landslide geological hazards with broad applicability is the foundation and key to improving the service life of gas pipelines in landslide prone areas and the accuracy of pipeline landslide geological hazard warning.

Chinese and foreign scholars have conducted a series of studies on the deformation and failure of pipelines under the action of landslides. For example, in terms of physical model testing, Calvetti F et al [1] The mechanical response of pipelines under landslide action was analyzed through small-scale indoor physical model experiments; Lin Dong [2] A large-scale interaction model between soil landslides and pipelines was established through artificial accumulation, and the deformation characteristics of pipelines under landslide action were analyzed; Niu Wen qing [3] The deformation law of pipelines located at different positions within the landslide body subjected to lateral landslide action was studied through physical model experiments; In terms of the influencing

factors of pipeline deformation, Hao Jian bin [4] The thrust of landslides on pipelines in a transverse state has been calculated, and it is believed that the thrust of landslides on pipelines in a transverse state is mainly affected by the diameter of the pipeline, the depth of the pipeline burial, and the properties of the landslide soil; Han B et al [5] The finite element method was used to simulate the changes in stress and deformation of pipelines under unstable slope movement. It was found that the deformation of pipelines under unstable slope movement is mainly affected by the rock and soil characteristics of the slope and the speed of slope movement; Tang Jun jie [6] By comparing the deformation patterns of pipelines crossing landslides horizontally, vertically, and obliquely, it was found that pipelines crossing landslides are the most dangerous; Regarding the deformation of pipelines under landslide action, Jiang Ke [7] An analysis was conducted on the lateral landslide effect on the pipeline, and it was found that the deformation deflection of the landslide pipeline is approximately a normal distribution; Tang Zheng hao [8] A force analysis was conducted on buried pipelines under the action of landslides, and it was found that small deformations caused by landslides may lead to pipeline damage, and the damage site is generally located in the middle of the pipeline; Vasseghi A et al [9] Finite element software was used to simulate geological hazards caused by pipeline landslides, and it was found that pipeline fractures mostly occurred at the circumferential weld seam in the middle of the double elbow; Wu Yu liang [10] After analyzing the impact of different pipeline crossing methods on pipeline deformation, it was found that when the pipeline crosses a landslide horizontally, its maximum deformation occurs at the center of the landslide section, while when it crosses a landslide longitudinally, its maximum deformation occurs at the bend pipe; The stress characteristics of pipelines under landslide action, Li Hua [11] The stress characteristics of pipelines under landslide action were studied using numerical simulation, and it was found that the top and bottom of the pipeline were subjected to the maximum stress; Hu Hai

yang[12]It is believed that the stress and axial strain of pipelines are positively correlated with their burial depth, and as the burial depth increases, the growth rate of pipeline stress and axial strain also increases; Zhang Y et al[13] Simulated the force of submarine landslides on pipeline laying at different impact angles, and provided expressions for the normal and axial impact forces of submarine landslides on pipelines; Li Hang hang[14]. Based on the DEM-FEM coupling method, the mechanical response analysis of pipelines under landslide action was conducted, and it was found that the peak force of landslide force on pipelines that occurred in a very short period of time after the start of the landslide was the main reason for pipeline failure and failure; Deng Dao ming[15]Derived the expression for calculating the internal force and displacement of the transverse pipeline under the action of landslides; Zahid U et al[16] Simplified the calculation process of pipeline strain under landslide action and proposed an analysis method to simulate the interaction between pipeline and landslide in natural gas pipelines. The above research mainly focuses on the failure mechanism of pipelines under landslide action, and does not consider the influence of specific geometric characteristics and dimensions of landslides on pipeline deformation. In terms of numerical simulation, it is also impossible to ensure the reliability of numerical model data of landslide pipelines under large deformation conditions.

Therefore, this article takes buried pipelines under landslide action as the research object, and based on the coupling technology of SPH (Smooth Particle Hydrodynamics) and FEM (Fine Element Method), numerical simulation experiments of pipeline deformation under different geometric feature sizes of landslide action are carried out. Comparative analysis of the deformation and failure characteristics of oil and gas pipelines under different burial positions, landslide lengths, widths, heights, and slope conditions. To provide reference for the construction and laying of oil and gas pipelines in landslide prone areas.

2. Overview of the Study Area

The pipeline location selected for this simulation belongs to the Guizhou section of the China Myanmar oil and gas pipeline. The terrain in this area is mainly plateau and mountainous, with complex geology, frequent crustal activity, high rainfall, and susceptibility to geological disasters such as landslides.

Based on the public data and published literature from the Guizhou Department of Natural Resources and the Guizhou Provincial Institute of Natural Resources Survey and Planning, it was found that landslides in this area have the following characteristics:

1. According to the quantity of landslide sources, the majority of landslides in this area are small landslides (small landslides account for 73.21%, medium landslides account for 23.21%, and large landslides account for 3.58%);

2. The landslides in the area are mainly soil (residual slope layer containing gravel and clay) landslides, accounting for 92.11% of the total, while rock landslides account for only 7.89%;

3. The slope gradient of landslides in the region is mainly concentrated between 10° and 30° , accounting for 81.58% of the total statistical quantity. Landslide disasters occurring with slopes less than 10° and greater than 40° only account for 5.26% of the total number of landslides;

4. The height difference interval where landslides frequently occur is $20\text{ m} < h \leq 50\text{ m}$, accounting for 55.26%; Next is $50\text{ m} < h \leq 100\text{ m}$, accounting for 23.68%; 21.05% of $h \leq 20\text{ m}$ and $h > 100\text{ m}$.

3. Numerical Simulation

3.1. Numerical model and parameters

Taking into account both computational efficiency and accuracy, this simulation adopts the coupling analysis technique of SPH and FEM to achieve large deformation. The specific idea is to transform the landslide mesh into particles, allowing the landslide to undergo large deformation, while the pipeline remains a finite element mesh to ensure the accuracy of the calculation results. The advantage of this scheme lies in its application of SPH technology, which avoids the problems of mesh distortion, calculation result distortion, and nonconvergence caused by large deformation of landslides. At the same time, the focus is on the use of finite element mesh calculation results on pipelines, ensuring accurate performance.

As shown in Figure 1, the model is divided into four parts: landslide body, stable soil, rigid boundary, and pipeline. The landslide body is the main sliding body, and the rigid boundary does not participate in the landslide process, only defining a range for the landslide.

The contact form between each model is natural contact, with rigid boundaries set as rigid bodies and full constraints applied (rotation and displacement are both 0). Gravity is applied to the pipeline and full constraints are applied at both ends. The soil parameters of the stable soil are set as parameters without strength reduction. The soil parameters of the landslide are set as parameters after strength reduction and a gravity field is applied.

Based on literature research data, this simulation mainly focuses on the design of working conditions for the most common types of landslides, with small soil landslides as the main focus. The specific working conditions are shown in Table 1. The landslide soil is cohesive soil, and the specific soil parameters are shown in Table 2, and the pipeline parameters are shown in Table 3. In order to simulate the process in which the stability of the slope soil decreases under the influence of rainfall until the slope slides, this simulation adopts the method of continuously decreasing the strength of the soil as time increases, which reduces the stability of the slope and finally begins to slide under the action of its own weight.

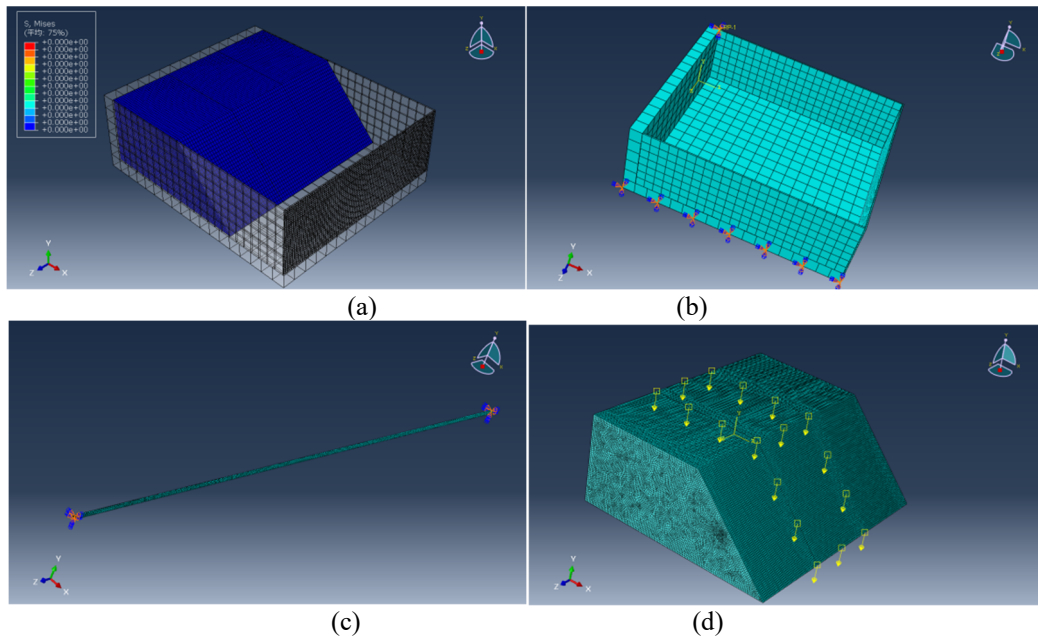


Figure 1. Numerical model

Table 1. Analog variable

Relative position of pipelines	Leading edge, middle, and trailing edge
Landslide height	20m、25m、30m
Landslide width	20m、25m、30m
Landslide slope	10°、20°、30°
Landslide length	50m、60m、70m

Table 2. Soil parameters

	Elastic modulus /MPa	density /g/cm ³	Poisson's ratio	internal friction angle /°	Cohesive force /kPa
cohesive soil	60.5	1.6	0.32	34	21

Table 3. Pipeline parameters

material	diameter /mm	wall thickness /mm	yield strength /MPa	Elastic modulus /MPa	Poisson's ratio	density /kg/m ³
X70 steel pipe	1016	12.5	485-605	2.1×10 ⁵	0.25	7800

3.2. Result and analysis

As shown in Figure 2, when the pipeline is located in the middle of the landslide, the displacement of the landslide has the greatest impact on the deformation of the pipeline, followed by the front and rear edges of the landslide, respectively. This is mainly due to the influence of soil thrust and support force on pipelines in landslides. The thrust in the middle of the landslide is relatively large, while the support force is relatively weak. Therefore, the deformation of the pipeline is relatively large. From the ellipticity, it can also be seen that the pipeline is most dangerous when located in the middle; From Figure 3, it can be seen that as the height of the landslide increases, the maximum deformation of the pipeline increases when the landslide experiences the same displacement. The impact of the landslide on the pipeline also increases. The analysis is that as the height of the landslide increases, the mass of the soil above the pipeline also increases. The same displacement increases the sliding slope thrust, which leads to an increase in the force on the pipeline and causes greater deformation. Combined with ellipticity, it can be concluded that the higher the height, the more dangerous the pipeline is; As shown in Figure 4, when the

width of the clay landslide is 25 and 30, the influence of pipeline deformation is not significantly different, both greater than the influence of width 20. Overall, the influence of width is not so significant. This result may be due to the lower sensitivity of width to the maximum strain of the pipeline. From the perspective of ellipticity, width 25 has the greatest impact and is much greater than width 20 and width 30. The impact of width on ellipticity is more significant. To clarify the impact of width, further simulations with larger scale differences are needed; Figure 5 shows that the larger the slope, the more significant the impact of landslide deformation on pipeline deformation. The reason is that the larger the slope, the greater the thrust the pipeline receives, making it more sensitive to landslide deformation. Combined with ellipticity, it can also be concluded that as the slope increases, the impact of landslides on the pipeline also increases; As shown in Figure 6, as the length of the landslide increases, the maximum deformation of the pipeline decreases when the landslide experiences the same displacement. Analysis suggests that the reason is that as the length of the landslide increases and the height remains constant, the slope of the landslide decreases. The smaller the

slope, the less impact the landslide has on pipeline deformation, which is consistent with the observation of slope. Combined with ellipticity, it can be concluded that when the

height is constant, the shorter the length of the pipeline, the more dangerous it is.

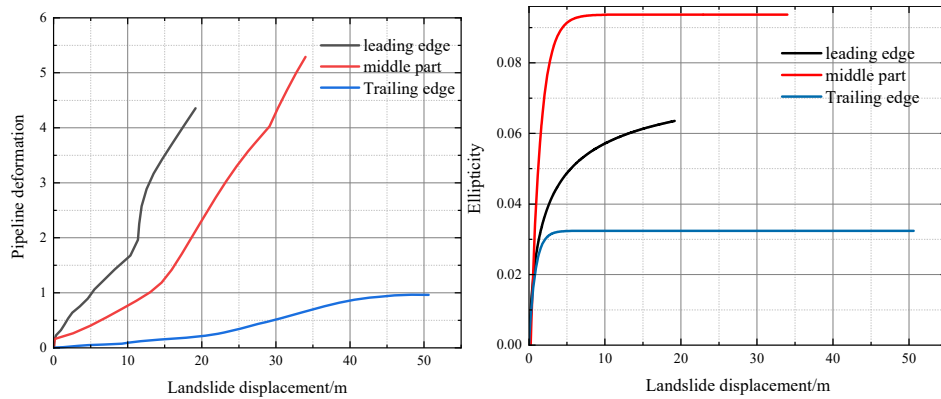


Figure 2. The influence of relative position between landslides and pipelines on pipeline deformation

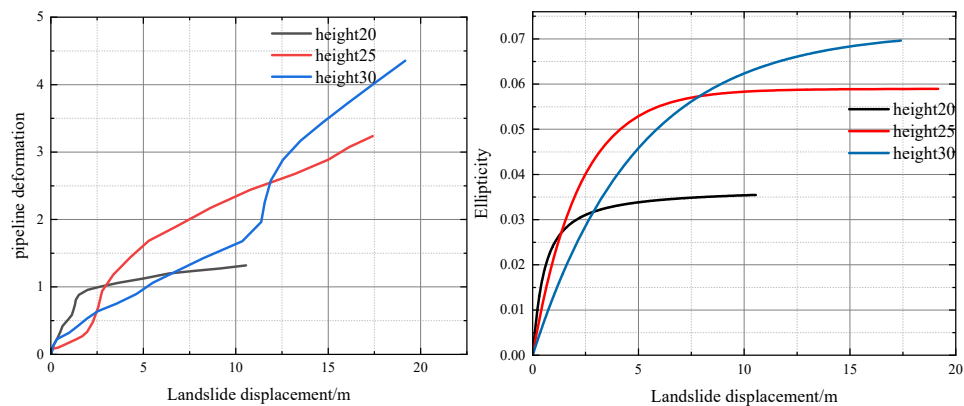


Figure 3. The influence of landslide height on pipeline deformation

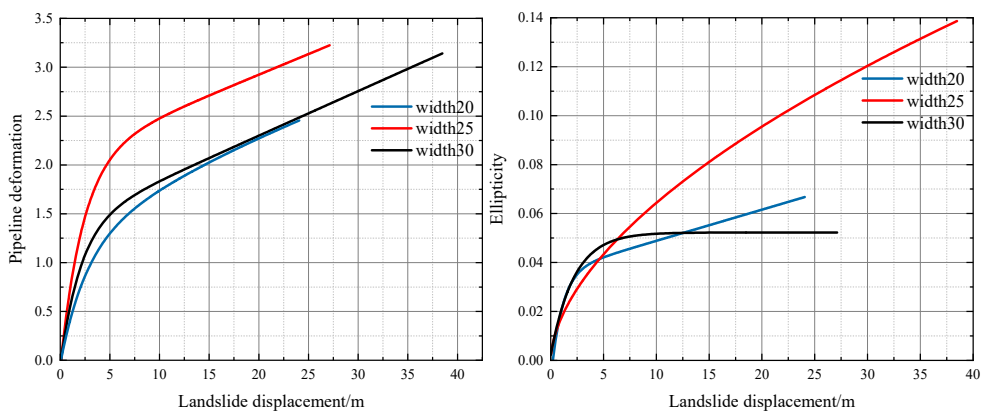


Figure 4. The influence of landslide width on pipeline deformation

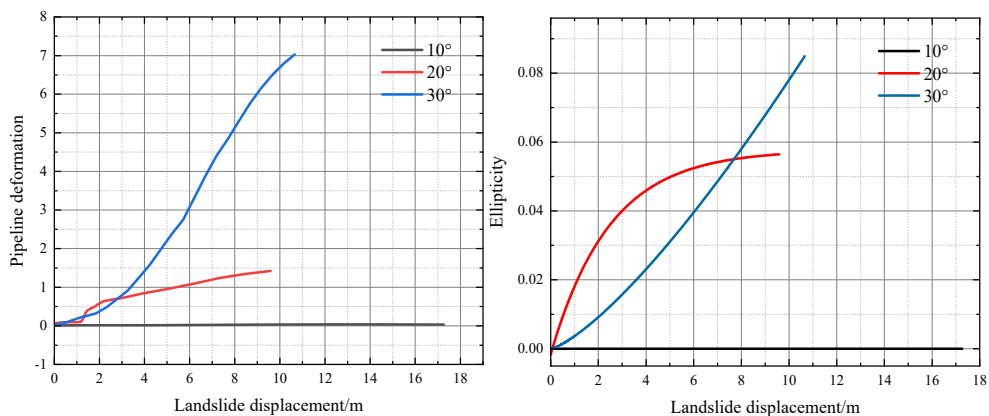


Figure 5. The influence of landslide slope on pipeline deformation

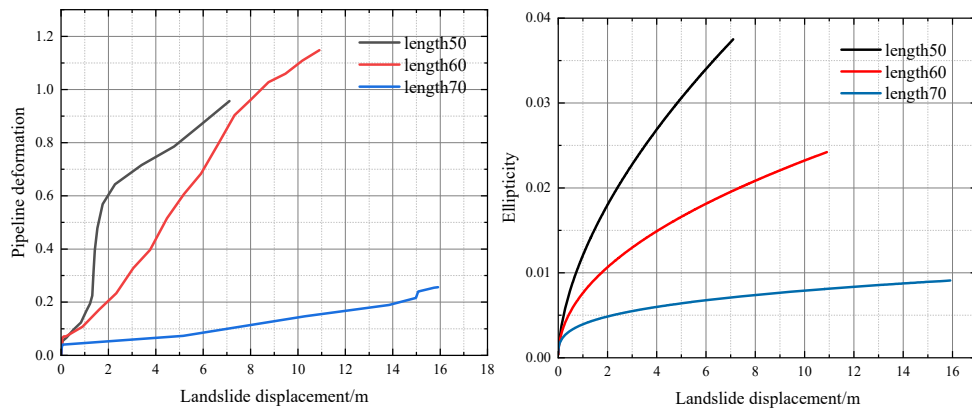


Figure 6. The influence of landslide length on pipeline deformation

4. Summary

This article is based on numerical simulation to conduct oil and gas pipeline model experiments under landslide conditions. The main conclusions drawn from studying the deformation and failure characteristics of pipelines under different burial positions, landslide lengths, widths, heights, and slopes are as follows:

(1) Research has found that the parameters of landslides, including the length, width, height, and slope of the landslide, as well as the relative position of pipelines and landslides, are the main factors affecting pipeline deformation. As the slope, height, and length of the landslide increase, the deformation of pipelines also increases.

(2) The use of SPH+FEM technology can achieve accurate simulation of the entire process of geological disasters caused by pipeline landslides. The simulation results can accurately reflect the deformation characteristics of pipelines under the action of landslides and obtain deformation data of pipelines during the landslide process.

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