# Study on the Deformation Characteristics of Oil and Gas Pipelines Subjected to Landslides

Jun Zhong[1,*], Hai Yu[2], Chao Li[1]

[1]China Petroleum Pipeline Engineering Corporation, Langfang, 065000, China
[2]Construction Project Management Branch of China National Petroleum Pipeline Network Group Co., Ltd., Langfang, 065000, China
*Corresponding author: 380674893@qq.com

**Abstract.** With the growing demand for energy, oil and gas pipelines play a vital role in the transportation of oil and gas. The terrain of our country is complex, and landslide is one of the main geological disasters causing damage to oil and gas pipelines. In this paper, a full-scale model test with small pipe diameters was carried out by controlling the slope gradient and displacement through a model box loading device, revealing the deformation law of oil and gas pipelines under transverse landslide. The research results indicated that under the action of transverse soil displacement, the increment of pipeline strain increases with the increase of displacement; obvious local buckling phenomenon occurs at the mid-span of the pipeline, and the overall failure form is symmetrical bending. The ultimate compressive strain value of the test is basically consistent with the calculated value in the specification, but the test value when the pipeline buckles and fails is significantly larger than the numerical simulation result. Finally, the friction coefficient between the pipeline and soil in the finite element model was corrected based on the scaled test data. By comparing the pipeline axial strain data from the scaled landslide test with that of the full-scale finite element model, the reliability of the finite element model was verified. This is of great significance for ensuring the safe operation of oil and gas pipelines and reducing losses caused by geological disasters.

**Keywords:** pipelines, landslide, transverse displacement, deformation, model experiments

## 1 Introduction

The deformation test and effect study of oil and gas pipelines under the action of transverse landslide is a complex and important topic, which involves the threat of landslide geological disasters to the safe operation of oil and gas pipelines. Theoretical analysis and numerical simulation are the basic methods for studying the interaction between landslides and pipelines [1-3]. Theoretical analysis involves numerous assumptions, and its results are only applicable to materials in the elastic stage, making it difficult to apply to pipelines passing through large deformation sections such as landslides. Numerical simulations often employ soil spring models or solid contact models, which involve significant simplifications and can lead to grid distortion during large deformation calculations, reducing computational accuracy. Therefore, it is an effective method to conduct model tests on the interaction between pipe and soil in the moving section of the slope using large-scale landslide models [4-6]. At present, most of the model tests simulate the pipe-soil interaction under strike-slip faults through soil boxes, resulting in the lack of slope solid calculation models. For example, Trautmann and O'Rourke conducted a series of full-scale tests on pipe soil interaction using a soil box with a length, width, and height of 1.2 × 2.30 × 1.20 m for pipelines with diameters of approximately 110mm and 220mm, and provided a calculation method for pipe soil interaction under dense sand conditions according to ASCE specifications. Ashrafy used 1.5×1.5×8m soil box models and steel pipes with diameters of 113 mm and 218 mm, simulating the interaction between pipe-soil under strike-slip faults. The results show that the maximum load and initial stiffness of the soil on the pipeline are greater than those recommended in the ASCE guidelines [7-10]. This paper focuses on the characteristics of oil and gas pipelines crossing landslides. Utilizing a large-scale landslide model test platform, it conducts model tests on the interaction between the pipeline and soil in the moving section of the slope. The aim is to reveal the deformation and failure patterns of pipelines during landslide occurrence, and provide a scientific basis for establishing safety design criteria for pipelines in areas prone to landslides in mountainous regions.

## 2 Model test of Compacted Sand

### 2.1 Model Experimental Scheme

Reasonably designing soil and pipeline models, conducting indoor physical model tests, and utilizing model test methods to simulate pipe-soil interaction are effective ways to reveal the deformation and failure patterns of pipelines during landslide processes. According to the size of the model box of the test platform, the design slope size is 4.2m (length) × 1.05m (width) × 0.9m (height), and the slope angle is set to 30°. The pipeline is buried at the slope shoulder position, and the buried depth at the top of the pipe is 0.4m. The total length of the pipeline is about 1.5m, the length in the soil is 105cm, the thickness of the model box is 2.5cm, and the suspended part of the pipe extends from each end of the pipe is 20cm. The steel pipe selected for this test pipeline is Q235 galvanized seamless steel pipe, and the 40mm pipe diameter is selected for the test with an increased pipe diameter, which needs to be re-opened in the side wall of the model box.

### 2.2 Loading Process and Data Collection

After the model is made, the model is left to stand for 48 hours, and the loading test is carried out after the whole slope is consolidated and stabilized. Throughout the process, the data is recorded using an acquirer. After the model is stabilized, the graded slope is lifted, the slope of each climb is 5°, and the model is stationary after each climb, and the angel model is re-stabilized after the climb. Before and after the trial, the data were recorded. When the slope rises to 30°, displacement loading is performed. Due to the lack of precise control means of the loading device, the loading adopts a one-time loading until the displacement load causes the pipe to be destroyed. During the whole test, the data is continuously recorded, and a multi-camera camera is used to record the deformation process of the entire slope for analysis.

### 2.3 Analysis of Pipeline Calibration Test Process and Results

For the pipeline selected for the model test, in order to obtain its mechanical parameters and performance indicators, the same steel pipe needs to be used for calibration test. The strain gauge is laid on the steel pipe, and then the three-point bending test of concentrated load is carried out. The initial preload is 0.5Mpa, and then 0.2Mpa is loaded each time, and the deflection value and strain value are recorded after 5min after each stage of loading is stopped and stabilized for 5 minutes, and then the next stage of loading is carried out until the model enters the plastic failure stage.

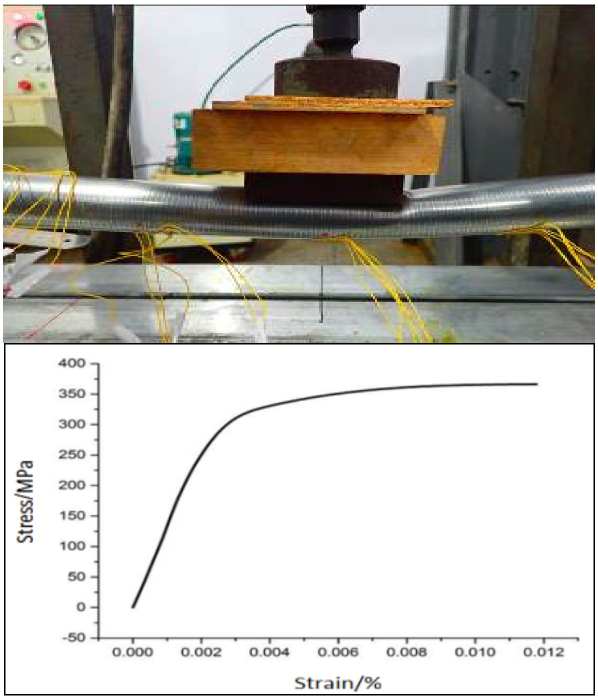


**Fig. 1.** Pipeline calibration test and the stress-strain curve of the test pipeline.

After the calibration test, the relationship between the strain value, deflection value and loading strength obtained by the test was processed by using the principle of material mechanics formula, and the stress-strain curve of the pipe was obtained (Figure 1).

## 2.4 Pipeline Strain Analysis

With the promotion of the lower jack of the model box, the angle of the bottom surface of the whole slope increases from 0° to 30°, and the load on the pipeline changes, which is manifested as the increase of slope thrust, and the strain data of each section responds obviously. The sliding side of the pipeline is in a state of compression, and most of the strain gauges of the pipeline are shown as negative values, and their values increase with the increase of slope, and the mid-span strain can reach about -1000 at 30°. The back-slip side of the pipe is in tension, and most of the strain gauges show positive values, which also increase with the increase of slope, and the mid-span strain can reach about +1000 at 30° (Figure 2). When the slope of the model box is raised to 30°, the steel plate behind the model box is pushed by the hydraulic servo controller to move forward to push the slope. In the process of moving, the slope interacts with the pipeline, and the pipeline changes significantly from the elastic deformation stage to the plastic deformation stage and then to yield failure. In the test process, it is found that the slope movement is more integral, and the displacement of the thrust plate behind the model box is regarded as the displacement of the landslide as a whole, and the change of the strain values of different cross-sections in the process of displacement loading is plotted as a variable.

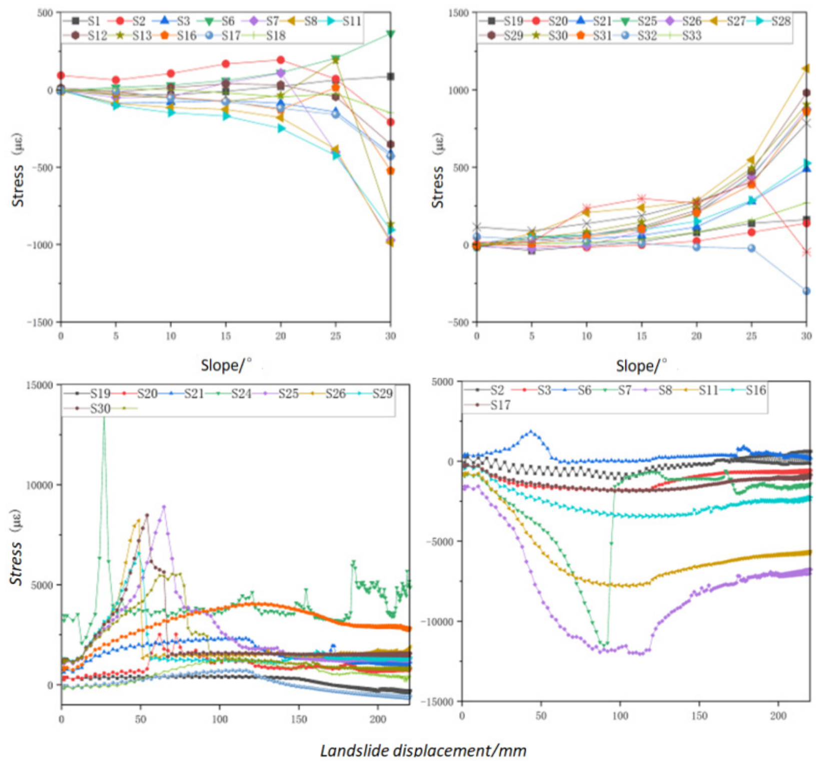


**Fig. 2.** Variation of strain values at different slopes.

## 2.5 Soil Stress Analysis Around the Pipe

The soil pressure value can also be divided into slope change stage and displacement loading stage according to different loading stages, and the change map of soil pressure monitoring data is drawn with slope and landslide displacement as variables respectively (Figure 3). The variation law of the soil pressure value in the four directions of the pipe, the pipe, the front of the pipe and the back of the pipe is different during the loading process, and the soil pressure value changes little in the process of ascending, and the obvious is that the soil pressure value on the slope side in front of the pipe increases with the increase of slope. In the process of displacement loading, the response of the soil pressure value in front of the pipe is the most obvious, and it increases with the increase of landslide displacement, and the maximum value can reach 380KPa.

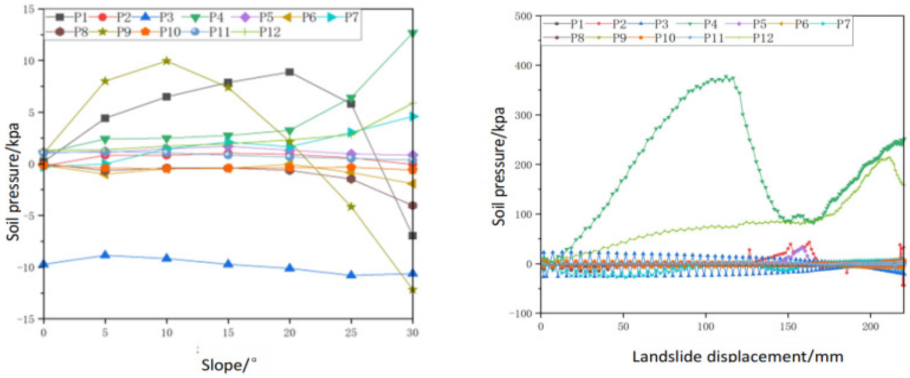


**Fig. 3.** Variation of soli pressure value monitoring data.

## 2.6 Analysis of Influencing Factors

In a specific engineering context, gas transmission pipelines exhibit material characteristics of large diameter and high steel grade. Therefore, selecting tensile strain as the mechanical parameter is instructive when evaluating the strength of pipeline structures within the scope of elastic-plastic mechanics, without considering fracture mechanics. To investigate the mechanism by which pipeline tensile strain behavior is affected by circular landslides, it is necessary to identify the influencing factors. By compiling factors analyzed by scholars regarding pipeline mechanical parameters under landslide conditions, it was discovered that the primary influencing factors encompass pipeline parameters and landslide parameters. Firstly, by identifying the factors that influence the calculation of pipeline strain in the slope movement section, all types of influencing factors are determined. Subsequently, a dimensionless analysis is conducted for each type of factor to establish the dimensionless expression form of the final strain calculation model. Then, using the control variable method, the study focuses on the impact of individual factors on pipeline strain, specifically examining their mechanical behavior. By observing the trends in change, a functional expression for the influence of each factor on pipeline strain is determined. Furthermore, the coupling effects among these factors are discussed. The strain calculation model's effectiveness is tested, and a new working condition is devised for further testing. In this study, we focus on eight commonly used pipe diameter parameters in engineering projects: D219, D406, D610, D813, D914, D1016, D1219, and D1422. For each of these diameters, we conducted corresponding mechanical behavior research. Excluding factors other than the diameter-to-thickness ratio, the results are presented in Figure 4. As evident from the figure, within the same pipe diameter range, as D increases and grows linearly within the D/t ratio, the impact of other influencing factors on the strain trend remains relatively unchanged.

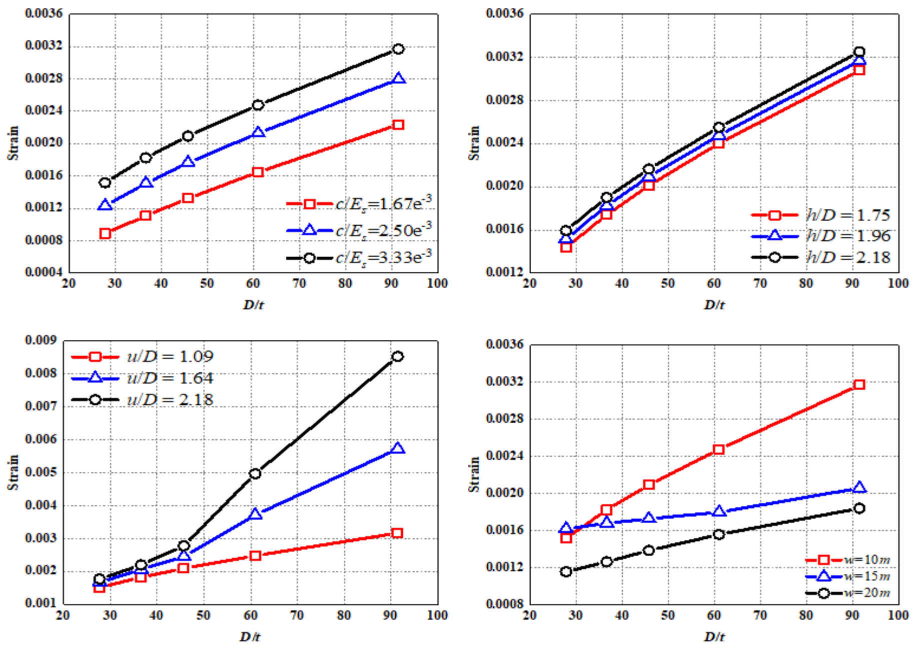


**Fig. 4.** Study on horizontal mechanical behavior of other influencing factors 3 under different diameter thickness ratios.

Under the influence of different aspect ratios, the maximum tensile strain exhibits a linear relationship with the depth-to-diameter ratio. When the diameter-to-thickness ratio of the pipeline is small, meaning the wall thickness is relatively large, the growth rate of the pipeline's maximum tensile strain initially increases and then decreases as the maximum landslide displacement increases. When the diameter-to-thickness ratio is large, the growth rate of the maximum tensile strain remains relatively constant and exceeds that of the smaller ratio. Specifically, with a diameter-to-thickness ratio of 25.4, when the maximum landslide displacement increases fivefold, the maximum tensile strain only rises by 40%. However, at a ratio of approximately 76.2 (three times the original ratio), a fivefold increase in maximum landslide displacement leads to a 304% increase in maximum tensile strain. Landslide displacement, a natural disaster, is difficult to intervene with human efforts, but increasing the wall thickness by three times can significantly reduce the maximum tensile strain. Therefore, this measure is highly effective in mitigating the axial tensile impact on pipelines caused by large soil displacements due to landslides. In practice, the maximum tensile strain initially increases and then decreases as the aspect ratio increases. This phenomenon occurs because, when the landslide width is small, the maximum tensile strain occurs at the junction between sliding and non-sliding soils; as the landslide width increases, the maximum tensile strain occurs at the center of the sliding soil. In engineering qualitative evaluations, a quick conclusion can be drawn: under the same other conditions, the larger the width-to-diameter ratio, the smaller the maximum tensile strain produced by the pipeline.

## 3 Verification of Test Model

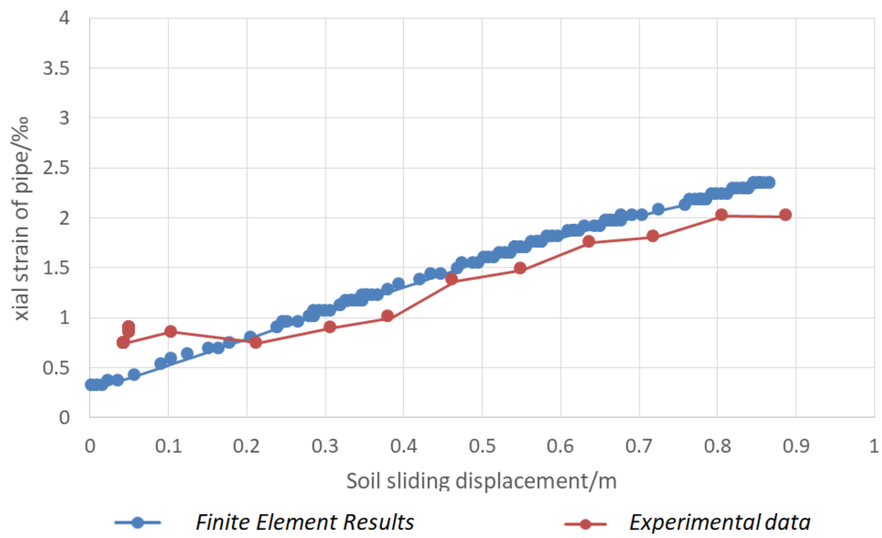


**Fig. 5.** Comparison of strain on the middle and outer sides of the pipe span.

The full-size large-diameter pipeline can be selected as OD1219mm×18.4, and the scaled test diameter is 40mm, so the similarity ratio is about 30:1. A numerical calculation model is established using ABAQUS software, and the steel pipe material is X80 steel. The contact type is surface to surface contact. The normal contact is defined as hard contact, the initial tangential friction coefficient is defined as 0.3, and the element type between the pipeline and the soil is defined as C3D8R.The strain data in the test data is the most reliable, and the strain data of the pipeline at 3/4 span is relatively stable, so the axial strain data is compared, and the friction coefficient between the pipeline and the soil is modified after many trial calculations, and it is found that when the friction coefficient is set to 0.25, the finite element results can be consistent with the test data, and the results in the figure have modified the coefficient. The outer and outer sides of the figure refer to the tensile side of the pipeline span when deformation, and the inner side refers to the compression side, and the test data of the inner and outer sides of the pipeline span are measured by No. 34 and No. 16 strain gauges respectively, and the test data are 1:30 according to the scaling ratio Zoom in to facilitate comparison with finite element results. The test data are consistent with the finite element calculation results (Figure 5), and the finite element results are more conservative than the test data, and the material, boundary conditions, diameter-thickness ratios and other local dimensions between the two do not fully meet the similarity ratio, which affects the results to a certain extent.

## 4 Conclusion

The reliability of the finite element model was verified by comparing the axial strain data of the pipeline between the landslide scale test and the original size finite element model. The friction coefficient between the pipe and soil in the finite element model was corrected through scaled test data. The conclusions of this study are as follows:

(1) Under the action of transverse soil displacement, obvious local buckling phenomenon occurs at the mid-span of the pipeline, and the overall failure form is symmetrical bending, the increment of pipeline strain increases with the increase of displacement. In the engineering design stage, larger wall thickness or strain design method can be used to increase the strain capacity of the pipeline.

(2) The ultimate compressive strain value of the test is basically consistent with the calculated value in the specification, but the test value when the pipeline buckles and fails is significantly larger than the numerical simulation result. When using numerical tools to calculate, the coefficient should be increased to make the design scheme safer.

(3) The pipeline should try to avoid passing through sections with a slope greater than 20 ° at the design stage, and necessary protective measures should be taken to protect the operation safety of the pipeline. A study of pipeline protection measures should be carried out in the future, such as the installation of cushioning devices in areas where lateral landslides may occur. The buffer device is capable of effectively absorbing the displacement of the landslide. At the same time, it lowers the strain value of the pipeline and strengthens the pipeline's ability to resist the deformation induced by the landslide, thus ensuring the safe operation of the pipeline.

## Acknowledgments

This work was financially supported by the funds of "Research on Safety Design Technology of Oil and Gas Pipelines in Mountainous Areas" (GK22-A-2) and "Pipeline Integrity Management in Strain Design Areas" (20221256126).

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