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Failure analysis and safety evaluation of buried pipeline due to deflection of landslide process

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ABSTRACT

This paper focuses on the failure mechanisms of buried X65 pipeline due to non-uniform deflection of landslide process. First, fractographic tests are performed to analyze the failure causes of two typical accidents arising from landslide. Second, based on the non-linear stabilization algorithm, an improved finite element model is established to predict the load-bearing ability of buried pipelines under deflection load, and the nonlinear contact interaction between the pipeline and soil is considered. Particularly, effects of the surrounding soil, internal pressure and pipeline geometry are comprehensively investigated for the risk assessment of buried pipeline under large deflection. Finally, a strength failure criterion based on the maximum principal strain is proposed to determine the safe properties of buried pipeline under this special failure issue. Research in this paper can provide technical support for the safety assessment and standard formulation of buried pipelines.

1. Introduction

With the increasing demands of global energy resources, buried pipelines for natural gas transportation are facing good opportunities to make great progress. Buried pipelines, which often run in high pressure and harsh environment, have posed severe challenges to the life prediction and safety evaluation [1,2]. Therefore, it is imperative that the fundamental research of failure mechanisms should be developed rapidly.

Safety issues of buried pipeline under permanent ground deformation such as fault movements and landslides have aroused wide attention in these years. Under these special failure issues, buried pipelines are often subjected to excessive plastic deformation which is associated with additional axial, shear and bending loads, and the high stress/strain on the pipeline can finally result in local plastic collapse or local buckling at the critical location.

Already, safety problems of buried pipeline under the active fault movements of earthquake have been studied for many years. Newmark and Hall [3] first investigated the mechanical properties of buried pipeline due to large crossing fault, and the pipeline was simplified as a long cable. Kennedy et al. [4,5] improved the model in order to explore the non-uniform friction behavior between the pipe and its surrounding soil. Wang et al. [6,7] investigated the bending stiffness of buried pipelines during the fault movements. Takada et al. [8] proposed a simplified method for calculating the critical strain at longitudinal direction. Trifonov and Cherniy [9,10] presented a semi-analytical approach to analyze the mechanical behaviors of buried pipeline, which comprehensively considered the nonlinearities of material, large displacement and pipe/soil interaction. In the past decades, the finite element method was widely used to simulate the buried pipeline behaviors under permanent ground-induced actions. Karamitros et al. [11,12] employed shell elements to describe the pipeline, and the surrounding soil was simulated by nonlinear springs. The numerical results by finite element analysis were compared with

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the current analytical methods, and the distribution of axial strain along the pipeline was obtained. Vazouras et al. [13] and Zhao et al. [14] applied similar models to explore the failure properties of pipelines under different directions of fault movements.

However, little work was concentrated on the failure mechanisms of buried pipeline due to non-uniform deflection arising from landslide. In fact, accidents of buried pipeline in the landslide area occurred frequently in these years. In 2008–2009, two accidents appeared continuously in Zhejiang province of China. The pipelines developed excessive plastic deformation, which finally resulted in local plastic collapse at the critical location. Liu et al. [15] proposed a finite element method to predict the load-bearing ability of these pipelines, yet the contact boundary condition was not applied on the interface between the pipeline and its surrounding soil. Furthermore, since the fractography and the effects of some significant factors were not investigated in that paper, the strength failure criterion of this failure issue cannot be proposed.

Thus, in this study, the fractographic testing is first carried out to analyze the failure causes of two typical accidents. Second, the contact boundary is applied on the interface between the pipeline and soil in the finite element analysis. Particularly, effects of some factors such as the surrounding soil, internal pressure and pipeline geometry on the load-bearing ability are comprehensively investigated. Finally, a strength failure criterion of this failure issue is proposed, which can provide theoretical support to determine the allowable strain in the pipeline design process.

2. Two accidents of buried pipeline

In 2008–2009, two typical accidents of buried pipeline caused by landslide appeared in Zhejiang province of China. The earlier accident happened in Yuyao city, where the maximum deflection displacement reached about 1.9 m [15]. Fortunately, the offset segment of pipeline was detected timely and replaced before leaking. The latter accident occurred in Ningbo city as shown in Fig. 1. Terribly, the pipeline exploded at last. The site inspection indicated that the accumulated soil was deposited on the hillside, and the pipeline segment and its surrounding soil were severely pushed away from the original location during landslide process in rainstorm days.

Caption near the fracture location is shown in Fig. 2. As indicated in the picture, the pipeline is ruptured circumferentially in the butt-welded joint. The outer diameter of the fracture surface is 813.6–814.3 mm, which is close to the original value.

Fig. 1. Pipeline accident in Ningbo city of China.

Fig. 2. Captions near the fracture location of accident pipeline.