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A Review of the Research on the Role of Pipe-soil under the Action of Uneven Settlement

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Abstract

With the transformation of China's energy structure, the proportion of natural gas with buried pipeline as the main mode of transportation is gradually increasing. The natural gas pipeline has a long laying distance, the terrain is relatively complex, and is greatly affected by the external environment, such as ground load, tunnel construction, earthquake, etc., uneven settlement is easy to occur together with the soil, which may lead to pipeline damage and serious accidents. This paper sorts out the theoretical analysis, test and numerical simulation of the interaction of buried pipes under the uneven settlement of the ground, and puts forward the research of the soil interaction.

Keywords

Uneven Settlement; Pipe Soil Interaction; Buried Pipe.

1. Introduction

For a long time, China has been a big consumer of energy, and coal occupies an important position in the energy structure, so it has caused serious environmental problems in the process of development. Because of its clean, environmental protection and high utilization efficiency, natural gas is the first choice for China to transition to low-carbon and clean energy. According to China's medium-and long-term oil and gas pipeline network planning target, by 2025, the scale of China's oil and gas pipeline network will reach 240,000 kilometers[1], of which the natural gas pipeline will reach 160,000 kilometers, with an annual growth rate of 9.8%. On the one hand, long distance buried pipeline inevitably need to cross the frequency of geological disasters, all kinds of landslide collapse will seriously affect the construction and operation of buried pipeline safety, on the other hand, with the development of urbanization, urban underground water level, ground traffic load and the construction of underground rail transit will lead to a certain degree of ground subsidence, the pipeline suffered different degrees of damage, and cause a major accident.

The settlement failure of buried pipeline is a highly nonlinear dynamic evolution process [2]. Ground subsidence can be divided into small-range settlement and large-range settlement. In the process of large-range settlement, the pipe soil will be transformed from cooperative deformation to non-cooperative deformation. During settlement, the soil experience produces resistance and support force to the pipeline, and the pipeline produces deformation, which in turn acts on the soil. The interaction effect determines the deformation and failure mode of the pipeline. There are many factors affecting the damage of soil on pipeline, including the type of soil, density of soil, settlement degree of soil, pipe diameter, pipe thickness, buried depth of pipe, type of pipe, etc. Therefore, the deformation and destruction mechanism of pipe-soil interaction is the key factor affecting the structural design of buried pipelines. Many scholars at home and abroad have deeply studied this problem through theoretical analysis, model test and numerical simulation methods.

2. Study on Soil Action of Tube under Uneven Settlement

Since 1960, there has been more research on the damage to buried pipelines. The study of pipeline was first proposed by Newmark[3], who believed that the deformation of pipeline and soil occurred synchronously, and proposed the approximate calculation method of buried pipeline reaction. However, this method ignored the influence of inertial force of pipeline and was only applicable to small deformation. Since then, the research on the interaction between pipe and soil has developed rapidly. The pipeline has experienced the change from beam model to cable model and then to shell model, and the soil model has experienced the development from soil spring, to elastic-plastic, and then to viscoelasticity. So far, there are three methods for the analysis of tube-soil interaction under the action of uneven settlement: theoretical analytical method, test method and finite element method.

2.1 Theoretical Analysis

Theoretical analysis method usually regards the pipeline as the beam model and the cable model, and the elastic foundation beam model is commonly used, among which the classical one is the Winkler foundation beam model. When the length of the stratum collapse area is small, the Winkler model can be used to analyze the deformation and stress of the pipeline to simplify the calculation. When the stratum collapse area is large, the foundation soil may have a large deformation. The Winkler model does not consider the plastic deformation of the soil, and the result may not necessarily reflect the actual engineering situation. The elastic-plastic foundation beam model can simulate the interaction between pipe and soil during large deformation, but the calculation is complicated.

Ariman[4]established the flexion deformation and destruction model caused by the large deformation condition of the soil to the buried pipeline. Combined with the nonlinear thin shell theory, considering the plastic deformation of the soil, applying no boundary conditions on the soil transverse, and determining the critical fracture deformation of the pipe near the excavated fault.Zhang Tuqiao [5], Shen Wenming [6] et al. used Winkler elastic foundation beam model and Pasternak two-parameter foundation model to establish the longitudinal mechanical model of buried pipe and culvert under the differential settlement of foundation, and studied the longitudinal mechanical properties of buried pipe under the differential settlement of foundation.Gao Huiying [7] will be buried pipeline can be divided into settlement area and the settlement area, the elastic foundation beam analysis, settlement area using the three curve equation to simulate the geometric deformation, and through the settlement area and settlement area interface boundary conditions and mechanical coordination conditions for the pipeline displacement and internal force curve equation.Based on [8] Winkler foundation beam model and elastic-plastic foundation beam model, the geometric large deformation mechanical formula of pipe-soil interaction is established, and the nonlinear theory is used to solve the mechanical formula. The critical collapse length and application range are compared with specific examples.Zhao Huan [9] deduced the displacement and internal force equation of the pipeline in the elastic foundation beam model under the action of uneven settlement of the backfill soil. According to the example results, it shows that the influence of small-range uneven settlement on the pipeline is limited, and only affects the pipeline at the junction of differential settlement.Xu Ping [10] obtained the settlement deformation law along the pipeline based on the probability integration method, and established the cooperative deformation condition of pipe and soil in mining subsidence. On this basis, the mechanical analysis model of pipe-soil coordination and non-cooperative deformation is established, and the calculation formula of the additional stress of the buried pipeline is given.Zhu Yanpeng [11] Based on the pipeline displacement and internal force curve equation derived by the elastic foundation beam and the cubic curve equation, he derived the axial stress formula considering the internal pressure. The calculation shows that the maximum stress of the pipeline in the subsidence area is mainly composed of the axial stress generated by the internal pressure and the bending stress and axial stress generated by the subsidence action, and the pipeline in the non-subsidence area mainly bears the axial stress generated by the internal pressure.Ding Qingpeng [12] studied the buried pipeline in a wide range of settlement and small settlement of force and deformation characteristics, fully consider the tube soil from collaborative deformation to the collaborative deformation of two states,

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and established the corresponding mechanical simplified model, concluded that the pipeline damage stress damage criterion and strain damage criterion.

2.2 Experimental Investigations

Pipe and soil interaction test is divided into outdoor in-situ test and indoor zoom model test. Due to the special shape and limitations of the pipeline itself, the in-situ test is limited by many conditions, and most indoor model test is used for research.Takada Zhilang[13] carried out a large number of indoor soil box subsidence tests, and found that the maximum stress and maximum strain of the pipeline appeared near the discontinuous interface, the top and bottom stress of the pipeline was greater than on both sides of the pipeline, and the maximum stress of the pipeline and the settlement of the site were linear relationship.Chen Zhilei [14] by making ratio 1:1 test simple model, for different pipe diameter, wall thickness of PE pipe under uneven settlement deformation failure test research, test shows that under the same pressure with the pipe diameter of pipe settlement deformation decreases, and in the site subsidence wall thickness in the case of the stability of the pipe is better.Zhou Min [15] actually simulated the damage of the pipeline under the uneven settlement deformation through the geotechnical test, and obtained the evolution relationship between the axial and annular deformation of the PE pipe at different settlement depths, and found out the most unfavorable position of the pipeline damage under the uneven settlement deformation of the site.Xu Ping [16] et al. designed and developed a system for the soil interaction in the process of soil subsidence, and used the cable displacement meter to detect the coordination of the soil deformation, and completed the deformation of the soil pressure around the pipe and the deformation of the soil in the process of the soil subsidence.Wang le [17] through the test to simulate the seamless steel pipe in uneven settlement, and fault and the coupling pipe damage process, the pipeline strain value, deformation curve and pipe force characteristics, and concluded that under the same settlement, the pipeline force and deformation are larger than the single action under test results, shows that the coupling pipeline is more likely to destroy, not a simple superposition of two effects.Kangxun [18] using resistance strain measurement method of settlement pipeline dynamic stress and static stress monitoring, in order to obtain pipeline stress strain distribution and stress concentration condition and the change of pipeline dynamic stress over time, and simulate the stress value of each key node, to verify the accuracy of the test.

2.3 Numerical Simulation

Soil spring model and nonlinear contact models are two commonly used FEA models. The soil spring model uses the soil as the soil spring, and then the equivalent spring boundary is used to study and treat the buried pipeline. The parameters of the soil spring can be determined by analytical method, experimental method and finite element method, which is relatively simple and widely used. The nonlinear model considers the nonlinear problem of pipe and soil and pipe and soil contact, including geometric nonlinearity, material nonlinearity, and state nonlinearity.

Shi Yongxia [19] uses the finite element method of shell model to analyze the response of buried pipeline under the action of subsidence, and considers the influence of nonlinearity of pipeline and soil materials and geometric nonlinearity of deformation. In the process of research, the soil medium around the pipeline is equivalent to a nonlinear spring in the vertical direction, and the subsidence of the soil is simulated by linear displacement loading, and the influence degree of different parameters such as subsidence length, pipe diameter, buried depth and soil parameters on the pipeline, and the law of pipeline stress and deformation are obtained.Hanbing [20] et al. adopted the Ramberg-Osgood constitutive relationship based on strain theory to establish the finite element simulation calculation model of oil and gas pipeline in goaf collapse area, and discussed the influence of two different theories based on strain and stress on the pipeline failure criterion in goaf collapse area.Luo [21] studied the relationship of pipe strength failure and settlement displacement based on ABAQUS simulation, and discusses the influence of transition length on pipeline yield.Zhang Yinan [22] et al. analyzed the influence of settling soil on the stress of pipe crossing structure, and established a model of pipe-soil interaction under the action of sedimentation. The results show that the maximum Von Mises stress

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in the crossing structure increases with the settlement range and the angle of inclined pipe.Zhang Jie [23] et al. Based on the large deformation of thin shell and the coupling effect of pipe and soil, the paper analyzes the influence of soil properties such as formation collapse, pipe wall thickness, buried depth, elastic modulus, Poisson's ratio and cohesion on pipeline mechanical response.Zhou Qichao [24] established the interaction model of the pipe soil in the station pipeline under the settlement, used ABAQUS software to analyze the stress changes under the settlement of different sites, and verified the accuracy of the finite element results on the pipeline by resistance stress method. According to the results, the formula of the maximum stress and the maximum settlement displacement is fitted.Wu [25] et al. established a finite element calculation model of large diameter backfill steel pipe, analyzed the soil contact state, steel pipe deformation, soil displacement and soil pressure around pipe under empty and full water conditions, and discussed the influence of pipe diameter and friction coefficient on steel pipe deformation and soil pressure around pipe.Liu Wei [26] used ABAQUS finite element analysis software to establish the model of two kinds of integrated pipelines and two kinds of undertaking pipelines, compared the settlement resistance of four kinds of pipelines, obtained the limit displacement of each pipeline under the action of settlement, and studied the relationship between the pipe diameter and the length of soil settlement area and the ultimate settlement displacement of the ground.

3. Conclusion

This paper systematically summarizes the research results of theoretical analysis and numerical simulation and the progress of related experiment research.

The analytical method mostly uses the elastic foundation beam model to analyze the problem of buried pipeline. With the rapid development of computer technology and numerical analysis theory, more and more scholars at home and abroad use the numerical simulation method to study the pipe-soil interaction problem of buried pipelines. To study the stress change law under the settlement state of buried pipeline, the numerical simulation method is more comprehensive, and the nonlinear problem of pipe soil material and pipe soil deformation can be taken into account. The experimental method includes indoor pipeline settlement simulation experiment and pipeline stress monitoring. Pipeline stress measurement can grasp the stress state of the pipeline itself in real time, and plays a very important guiding role in the analysis of pipeline body safety, pipe line operation management and risk assessment.

In the actual settlement process, not only the soil acts on the pipeline, but also the final destruction of the pipeline is the result of a combination of various factors, such as the pipeline operating pressure, ground vehicle load, corrosion aging of the pipeline, initial defects, temperature, etc. At present, the study of pipeline settlement failure considers relatively single factors, and the study of pipeline failure under multi-field coupling is the future trend. At the same time, there are many studies on the stress and strain of buried pipelines under multi-field coupling action, but the failure modes of pipelines are different under different coupling field conditions, and few people study the use conditions of the maximum tensile stress criterion and the maximum tensile strain criterion.

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