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Current Status of Research on Buried Gas Pipelines Containing Crack Defects

Mei Yang, Meng Yuan, and Yanhua Chen

North China University of Science and Technology, Tangshan 063000, China

Abstract

In China's energy structure, oil and gas occupy an important position. Due to the multiple limitations of oil reserves, environmental protection policies and social demand, clean energy such as natural gas has been widely used, of which buried pipelines have become one of the main ways of natural gas transmission. Defective pipelines containing cracks are an important cause of pipeline failure accidents in recent years, posing an important threat to the safe operation of buried pipelines. In this paper, from the three aspects of pipeline crack detection methods, pipeline cracking, and failure analysis and remaining life, the relevant research results of buried pipelines in recent years are sorted out, and further prospects for the subsequent research direction are proposed.

Keywords

Buried Pipeline; Crack Defects; Numerical Simulation; Remaining Service Life.

1. Introduction

With the sustained economic growth, the demand for natural gas in industrial production and residential life also shows a rapidly rising trend, and buried pipelines have become one of the main ways to transport natural gas. Compared with other transportation methods, oil and gas pipeline transportation shows obvious advantages in terms of investment, operation cost and loss. At the same time, studies have shown that large-diameter and high-pressure pipelines are preferred to large-diameter and high-strength high-steel-grade pipelines in practical engineering applications due to the wall thickness limitation problem [1].

Primary defects inherent in pipeline steel cannot be avoided, and various problems may arise from long-term service, and these pipeline defects constitute a potential safety risk for pipelines. At the same time, the expansion of cracks can be devastating, resulting in economic losses and human casualties that are usually incalculable. Pipeline accidents due to cracks exist all over the world, such as the steel natural gas pipelines in North America had suffered damages in which the cracks extended up to a distance of more than ten kilometers[2], the reason for which lies in the fact that the pipeline has been in service for a long time, and as the defects evolve into cracks, the pipeline instantly destroys under the pressure of more than ten MPa of gas in the pipe.

Therefore, an in-depth study of buried pipelines containing cracks is essential. In this paper, from the detection method of pipeline cracks, pipeline cracking, and failure analysis and remaining life of three aspects of the buried pipeline in recent years, the relevant research results are sorted out.

2. Detection Method

The core objective of gas pipeline safety monitoring is to provide continuous observation of the pipeline's operational status. When the pipeline faces a potential threat or a sudden safety accident occurs, it can quickly issue an alarm and accurately locate the location of the accident, so as to

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minimize the economic losses and slow down the further deterioration of the situation, and ultimately eliminate the potential risks posed by pipeline accidents.

Numerous scholars have mainly adopted a variety of methods centered on metal pipeline protection and applied them in actual engineering projects[3], including pressure gradient method, negative pressure wave method, flow balance method, ultrasonic detection method, magnetic leakage detection method, fiber-optic sensing, field fingerprint nondestructive monitoring (FSM), and other physical and chemical methods, which are different in their characteristics and application occasions[4]. According to the detection principle of the current mainstream pipeline accident determination monitoring technology is divided into: external patrol method, imaging technology, acoustic technology, fiber optic sensing several categories. Blue Chaosun[5] compared these categories of detection technology, see Table 1.

Table 1. Comparison of monitoring teehnologies

	Outside Line Patrol	Imaging method	Optical fiber sensing	Acoustical method
Monitoring content	Apparent leakage	Condition of the tube	Displacement, Leakage	Leakage
Monitoring accuracy	High	High	High	High
Monitoring scope	Small	Small	Big	Big
Technology costs	Low	High	High	High
Degree of commercialization	High	High	Low	High

3. Pipe Cracking

For the study of pipeline cracking and crack expansion, scholars mainly study it through experimental or numerical simulation methods. However, due to the limited experimental conditions, and in recent years the rapid development of finite element software, most scholars through the establishment of the relevant finite element model to carry out research.

Junnan Zhang et al.[6] carried out explosion modeling experiments on high pressure gas pipeline of X90 steel grade, and obtained the maximum crack extension rate.Mohamed Ben Amara et al.[7] investigated the maximum crack tip opening angle of pipeline by means of pipeline bursting test and numerical simulation of X65 steel grade.Kai Wu et al.[8] used experimental methods to investigate the maximum opening angle of fatigue crack extension of X70 steel and X80 steel materials. The maximum tension displacement and expansion velocity of fatigue crack expansion were measured and these data were utilized to assess the damage level of crack expansion in pipelines.

In 2020, Allan Okodi et al.[9] employed the extended finite element method (XFEM) to study crack propagation and burst pressure in pipelines with constrained and unconstrained concentric dent-crack defects. While results indicated that dent-crack defects posed relatively low integrity risks to pipelines under monotonically increasing pressure, the study only considered two crack depths without comprehensively examining dent-crack effects on pipeline integrity. In the same year, the author[10] further applied XFEM to investigate crack growth and rupture pressure in longitudinally cracked pipelines. Also in 2020, Atika Hossain Akhi et al.[11] calculated stress intensity factors (SIF) for buried cast iron pipes affected by external corrosion and cracks. Their study incorporated pipeline geometry, corrosion pit dimensions/shapes, and crack location/orientation, combining finite element analysis with analytical methods to solve SIF under diverse operating conditions.

Yanwei Lv [12] comprehensively used the theory of pipe-soil deformation under settlement, fracture experiments, and numerical simulation to study the damage law of buried pipelines.

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Dai Ziwei [13] used numerical simulation methods to study the dynamic fracture and crack expansion of pipelines when subjected to the impact of the explosion load, establish a finite element model based on the multi-phase coupling under the action of the explosion wave - soil - pipe - pipe gas and pipeline damage and fracture conditions, to analyze the damage of the buried pipeline containing defects under the action of the explosion wave, and finally put forward a prediction method for the buried pipeline containing defects after the impact of the explosion. method.

Deng Jie [14] used finite element software to establish a finite element model containing an initial semi-elliptical crack defect, and studied the influence of factors such as pipe diameter, internal pressure, insulation thickness and temperature difference between pipe and soil on the pipe stress in a positive temperature conveying pipeline in the permafrost zone. In addition, by adjusting the length and direction of the crack, the effects of the J-integral of the crack and the variation of the stress intensity factor K on the behavior of the defect were deeply explored.

Xinyu Li [15] investigated the stress-strain generated by the internal pressure of the pipe and the overhang length on the buried pipeline in the collapse zone by establishing a three-dimensional finite element model.

Yang Xi[1]conducted an in-depth analysis of crack propagation characteristics in X80 long-distance pipelines based on actual engineering cases. Additionally, the research examined how variables (e.g., crack arrestor length, thickness, and material grade) influenced crack arrest behavior in X80 gas transmission pipelines.

Zhu Renchi et al. [16] investigated the effects of single/double point defects on pipelines with spiral weld flaws and associated crack propagation. Their methodology integrated finite element simulations with wide-plate tensile experiments.

Duan Yuhang et al.[17] modeled a river-crossing gas pipeline suspension span containing crack defects. Their finite element analysis examined complex stress, strain distributions and crack driving forces characterized by the J-integral.

Mingjiang Xie et al.[18] developed a multilayer perceptron-based model for predicting fatigue crack propagation in buried pipelines subjected to rockfall impact loads. However, the limited sample size may constrain practical applicability, as real-world rockfall impacts exhibit complex variability that could reduce prediction scope and accuracy.

4. Failure Analysis and Remaining Life

Min Zhang [19] and others proposed a nonlinear Wiener degradation model for buried natural gas pipelines with crack defects considering the effect of stress. The model considers the effect of stress on the pipeline as a random variable to affect the degradation rate of the pipeline, and at the same time considers the individual variability. Compared with the residual life estimated by the traditional nonlinear Wiener degradation model, the model proposed by Min Zhang predicts the results with a smaller error and more reliable results.

Ma et al.[20] studied a section of buried pipeline that had fracture leakage. After macroscopic and microscopic observation of the pipe fracture, analysis of the chemical composition of the material, observation of the microstructure, experiments on the mechanical properties, and analysis of the stresses, the main causes of the pipe fracture were determined and the remaining service life of the repaired pipe was predicted.

Yan Dapeng [21] numerically analyzed buried defective polyethylene (PE) gas pipelines subjected to comprehensive ground loads during the toughness failure stage; and established a life assessment method for buried defective PE gas pipelines.

Ma Qiurong et al.[22] analyzed the effects of different steel grades and stress ratios on the crack expansion rate of submerged arc welded pipe by studying the fatigue crack expansion test of X60 and X80 steel grade submerged arc welded pipe. And the fatigue life of X80 gradeφ1219 mm×22.0 mm submerged arc welded pipe was analyzed and calculated by simulating the stopping condition.

5. Conclusion

For the buried pipelines containing crack defects, the relevant research results in recent years have been sorted out from three aspects: detection methods of pipeline cracks, pipeline cracking, and failure analysis and remaining life.

With the continuous progress of society and economy, the construction scale of the city is also expanding gradually, and the research on buried pipelines is also developing in the direction of multiphase coupling of soil body-pipe-pipe internal pressure-load (vehicle load, explosion load, impact load, etc.).

During the development of the finite element method, the idea of fracture mechanics is gradually added to finite elements, FRANC3D is a computational software developed by the Fracture Mechanics Working Group of Cornell University, USA, which can be used to compute the three-dimensional crack extension pattern and the fatigue crack extension life of an engineering structure under any complex geometries, loading conditions, and cracking patterns. In addition, it has interfaces with finite element software such as ANSYS and ABAQUS, which are helpful for the study of pipeline cracking.

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References

[1] X. Yang: *Research on Dynamic Crack Propagation and Crack Arrest of Buried Long Distance Gas Pipeline* (MS., Hunan University of Science and Technology, China 2021).

[2] Z. Zhuang: The Development and Application of the Dynamic Fracture Analysis Code for Crack Propagation in Gas Pipelines, *Engineering Mechanics*, Vol. 16 (1999) No.1, p.105–114.

[3] B. Zhao: Research Progress and Prospect of Oil and Gas Pipeline Operation and Maintenance Technology, *Chemical Management*, 2018 (16), p.162.

[4] Y.Z. Li, H.L. Zheng, S.M. Jia et al.: Status of Oil & Gas Pipeline Inspection and Monitoring Both at Home and Abroad, *Petroleum Science and Technology Forum*, Vol. 31 (2012) No.2, p.30–35, 75.

[5] C.X. Lan: *Research on Typical Failure and Monitoring Methods of Buried PE Gas Pipelines in Urban Area* (MS., Sichuan University of Science & Engineering, China 2019).

[6] J.N. Zhang, Y. Long, J.Y. Wu et al.: Experimental Study on Explosion Crack Initiation and Crack-Arrest of X90 Steel Grade High-Pressure Gas Pipeline, *Engineering Blasting*, Vol. 23 (2017) No.4, p.21–25.

[7] M.B. Amara, G. Pluvinge, J. Capelle et al.: Modelling Crack Propagation and Arrest in Gas Pipes Using the CTOA Criterion, *The Journal of Pipeline Engineering*, 2016 (4), p.243–255.

[8] K. Wu, H. Zhang, M.Y. Xia et al.: Fatigue Crack Growth Rate of High Strength Pipe Steels, *Materials Science Forum*, Vol. 898 (2017), p.725–729.

[9] A. Okodi, Y. Li, R. Cheng et al.: Crack Propagation and Burst Pressure of Pipeline with Restrained and Unrestrained Concentric Dent-Crack Defects Using Extended Finite Element Method, *Applied Sciences*, Vol. 10 (2020) No.21.

[10] A. Okodi, M. Lin, N. Yoosef-Ghodsi et al.: Crack Propagation and Burst Pressure of Longitudinally Cracked Pipelines Using Extended Finite Element Method, *International Journal of Pressure Vessels and Piping*, Vol. 184 (2020).

[11] A.H. Akhi, A.S. Dhar: Stress Intensity Factors for External Corrosions and Cracking of Buried Cast Iron Pipes, *Engineering Fracture Mechanics*, Vol. 250 (2021).

[12] Z.W. Dai: *Dynamic Fracture and Consequence Prediction of Pipeline External Blast Based on Multiphase Coupling Effect* (MS., Northeast Petroleum University, China 2020).

ISSN: 2414-1895 DOI: 10.6919/ICJE.202510_11(10).0002

[13] J. Deng: *Study on the Destruction and Safety of Buried Pipelines in Permafrost Regions* (MS., Liaoning Shihua University, China 2020).

[14] X.Y. Li: *Stress Analysis and Safety of Buried Pipeline in Subsidence Area* (MS., Liaoning Shihua University, China 2020).

[15] Y.W. Lv: *Study on Failure Law of Buried Pipeline with Defects Under Non-Uniform Settlement of Soil* (MS., Anhui University of Science and Technology, China 2021).

[16] R.C. Zhu, H.H. Zhu, H.L. Guo: Behavior Analysis on Strain and Crack Propagation of Buried Pipeline Containing Defects Under Tensile Stress, *Journal of Fuzhou University (Natural Science Edition)*, Vol. 50 (2022) No.04, p.553–559.

[17] Y.H. Duan, S.H. Dong, H.T. Wei, N. Yang: Safety Analysis on Girth Weld Crack Defect of River-Crossing Pipeline, *China Petroleum Machinery*, Vol. 51 (2023) No.06, p.143–150.

[18] M. Xie, Y. Wang, J. Zhao, X. Pei, T. Zhang: Prediction of Pipeline Fatigue Crack Propagation Under Rockfall Impact Based on Multilayer Perceptron, *Reliability Engineering & System Safety*, Vol. 242 (2024), p.109772. DOI: 10.1016/j.ress.2023.109772.

[19] M. Zhang, M.J. Liu, Z.S. Dong: Reliability Evaluation Method of Buried Natural Gas Pipeline Under Random Stress, *Industrial Safety and Environmental Protection*, Vol. 49 (2023) No.05, p.39–43.

[20] X.M. Ma, H.Y. Song: Fracture Failure Analysis and Residual Life Prediction of Buried Pipelines, *Hot Working Technology*, Vol. 50 (2021) No.09, p.148–151, 155.

[21] D.P. Yan: *Research on Reliability and Lifetime Evaluation of Buried PE Gas Pipeline with Cracks* (MS., South China University of Technology, China 2019).

[22] Q.R. Ma, Z.L. Jin, Z.M. Guo et al.: Study on Fatigue Life Prediction of High Pressure Oil & Gas Pipeline, *Welded Pipe and Tube*, Vol. 37 (2014) No.08, p.12–15.