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Experimental study on simulation platform of long-distance oil and gas pipeline impacted by collapse and falling rocks

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Abstract

Geological collapse and falling rocks are one of the main geohazards causing damage to buried long-distance oil and gas pipelines. In this paper, an impact damage test platform for oil and gas pipelines caused by collapsing rocks is developed. By varying the shape and weight of the falling object, as well as the falling height, the platform simulates the damage caused by different types of collapsing rocks to the oil and gas pipelines. It also allows the observation of the evolution of stress and strain, as well as macroscopic damage characteristics during the failure process of the pipelines. Experimental results indicate a positive correlation between impact force and the mass and falling height of the falling object, which is also influenced by the diameter of the pipeline. Steel pipes with diameters of 114mm and 406mm exhibit greater buffering effects from their own frameworks when struck by falling objects, resulting in better stability. This demonstrates a close relationship between the strength and deformation characteristics of different pipelines. By combining theoretical analysis with experimental research, the failure patterns of oil and gas pipelines under the impact of collapsing rocks are obtained, providing a theoretical basis for the implementation of reasonable protection measures for oil and gas pipelines in the field.

Keywords

Collapse geological disaster, Oil and gas pipeline, Platform, Failure mechanism.

1. Introduction

In the past decade, with the development of the national economy and the increase in industrialization, China’s demand for oil and natural gas has gradually increased, leading to a significant growth in the number of long-distance oil and gas pipelines in China [1-2]. According to China’s “Medium- and Long-Term Oil and Gas Pipeline Network Planning,” the national oil and gas pipeline network will reach 240,000 kilometers by 2025. However, due to ongoing urban planning and the construction of other infrastructure facilities, coupled with the flammable, explosive, and toxic characteristics of oil and gas media transported through pipelines, there are significant constraints on pipeline routing choices. Inevitably, in the process of building a national pipeline network, it is necessary to traverse sections with complex geological environments, active tectonic movements, and high-frequency occurrences of mountain disasters. Among them, the impact of collapsing rocks on pipelines is one of the major disasters that cause pipeline failure and damage [3]. Rocks rolling down from high places possess significant kinetic energy. Once they collide with buried high-pressure pipelines, they can easily cause pipeline damage. Minor impacts can create dents in the pipeline, while severe impacts can flatten the pipeline and cause leaks, leading to catastrophic environmental accidents [4]. In April 2005, the concrete cover above the Zhongxian-Wuhan Shunxi pipeline section was punctured by falling hazardous rocks, causing severe indentation and deformation in the pipeline [5]; In 2008, the collapsing rocks caused by the Wenchuan earthquake led to multiple optical cable disruptions on the Lanzhou-Chengdu-Chongqing oil pipeline [6]; In August 2015, the pipeline crossing the Lancang River frequently experienced collapses of large hazardous rock masses on both the left and right banks, with the largest fallen rock measuring approximately 1.2 meters in diameter, pushing the passive protective net to the brink of failure [7].

In recent years, research on the impact of collapsing rocks on buried pipelines has focused on several aspects: field case analysis and mechanical analysis [8], numerical simulation studies [9], and model test analysis to investigate the response mechanisms of buried pipelines under rockfall impact [10]. Wu Shijuan analyzed the motion path of falling rocks and the stress-strain patterns of the pipeline in the Lancang River pipeline crossing project [11]; Yao Anlin et al. used numerical simulations to analyze the stress and displacement patterns of buried gas pipelines under impact from falling rocks at different incidence angles [12]. Ma Xiaolei et al. combined finite element numerical simulations, impact theory, and probability analysis to study the stress distribution patterns of X80 buried pipelines with different wall thicknesses under the load of rockfall impact forces, and proposed a limit state design method based on these findings [4]. Overall, the aforementioned studies have not fully considered the shape, weight, and falling height of heavy objects to simulate the damage and destruction of different types of collapsing rocks on oil and gas pipelines. It is difficult to deeply reveal the evolution patterns and macroscopic damage characteristics, as well as the damage patterns under various factors.

Therefore, based on previous research, this paper aims to develop an impact and damage test platform for oil and gas pipelines under collapsing rocks. This platform will simulate the damage and destruction of oil and gas pipelines caused by different types of collapsing rocks, investigate the evolution patterns of stress and strain and macroscopic damage characteristics, and obtain the damage patterns of oil and gas pipelines under the impact of collapsing rocks. The findings will provide a theoretical basis for adopting reasonable protective measures for oil and gas pipelines in the field.

2. Experimental Setup

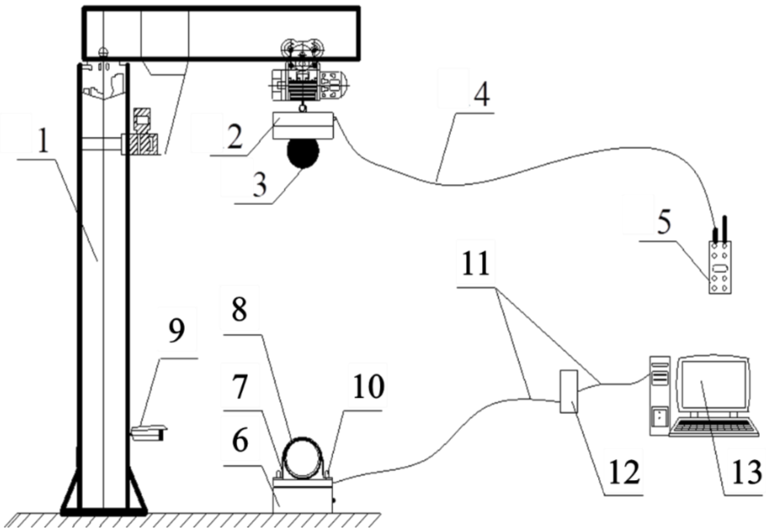
2.1. Experimental Platform Design

The experimental platform comprises a load-bearing system, a testing system, and a data acquisition system, as illustrated in Fig. 1.

Load-bearing System: This includes a cantilever crane, an automatic unhooking device, a remote control, and remote control wiring. The cantilever crane has a maximum height of 10.2 meters and a cantilever length of 3.0 meters. An automatic unhooking device is installed at the end of the cantilever, and an electromagnetic suction cup is mounted on the unhooking device to release the heavy object and allow it to fall in a free-fall manner.

Testing System: This consists of a high-speed camera, a force measurement platform, and fixing devices. The force measurement platform is used to test the change patterns of impact force experienced by the steel pipe after being hit by the heavy object. The high-speed camera is positioned at a height level with the steel pipe, below the cantilever crane, to record the process of extrusion deformation and even damage to the steel pipe.

Data Acquisition and Analysis Mechanism: This includes strain gauges, data cables, a data acquisition card, and a computer. The data acquisition card is connected to the strain gauges and the force measurement platform through data cables, allowing it to collect strain and stress values and transmit them to the computer via the data cables.



1- Cantilever Crane; 2- Automatic Unhooking Device; 3- Iron Ball; 4- Remote Control Wiring; 5- Remote Control; 61- Force Measurement Platform; 7- Fixing Device; 8- Steel Pipe; 9- High-Speed Camera; 10- Fixing Bolt; 11- Data Cable; 12- Data Acquisition Card; 13- Computer

Fig. 1 Schematic Diagram of the Collapse Platform

2.2. Selection of Relevant Parameters for the Force Measurement Platform and Data Acquisition Card

The relevant parameters and their respective values for the force measurement platform and data acquisition card are presented in Table1.

Table 1 Relevant Parameters for the Force Measurement Platform and Data Acquisition Card

Specifications	Technology Index	Specifications	Technology Index
Capacity	200t	Output impedance	700±10Ω
Rated output	1.5±1%mV/V	Insulation	≥5000MΩ/100VDC
Zero balance	±1% F.S.	Recommended excitation	5~15V
Non-linearity	0.1%F.S.	Maximum excitation	20V
Hysteresis	0.1%F.S.	Compensated temp range	10~40℃
Repeatability	0.1%F.S.	Operation temp range	10~70℃
Creep(30min)	0.05%F.S.	Safe overload	150%F.S.
Temp.effect on output	0.05%F.S./10℃	Ultimate overload	200%F.S.
Temp.effect on zero	0.05%F.S./10℃	Cable size	φ5×6000mm
Input impedance	780±20Ω	IP Class	IP66

2.3. Selection of High-Speed Camera

The estimated maximum flight speed of the object to be filmed is V=15m/s (equivalent to a heavy object falling freely from a height of 10m and reaching this speed upon impact with the ground). Assuming a field of view range of 2m×2m for the high-speed camera, the time for the object to enter and exit the field of view is approximately t=2/15=0.133s.

If the camera is set to capture at a speed of 2000 frames per second (fps), it will be able to capture 0.133s × 2000fps = 266 photos. This means that the displacement interval captured by the high-speed camera would be S=2m/266=0.0075m=0.75cm, or a displacement of 0.75cm between frames. This calculation can satisfy the filming requirements for the straight-line motion and impact of the heavy object.

By extension, it is recommended to adopt a filming speed of 2000fps or higher. Currently, based on actual research, the available camera types for selection are listed in Table 2.

Table 2 Selection of High-Speed Cameras

Structure	Manufacturer	Model	Quantity
Camera body	PHOTRON	FASTCAM UX50 4GB	1
Lens	Nikon	Nikon 35mm f / 2D wide-angle lens	1
Bracket System	Manfortoo	Manfutu 055 / 410	1
Analysis Software	PHOTRON	Photron FASTCAM Analysis	1

3. Experimental Platform and Experimental Procedure

3.1. Experimental Platform

The physical simulation platform for geological disasters such as oil and gas pipeline collapse has been successfully established, as shown in Fig. 2. Through the efficient cooperation of the load-bearing system, testing system, and data acquisition system, this experimental platform can observe the morphological changes of the oil and gas pipeline after being hit by different collapsing rocks, measure the variation patterns of stress and strain in the pipeline under different impact energy conditions, and obtain the criteria for determining the damage and failure of the pipeline under the impact of collapsing rocks. This provides a strong basis for adopting reasonable protective measures for oil and gas pipelines

（a）Overall architecture

（b）Data collection

（c）Heavy object model

（d）Oil and gas pipeline

(e) Plumb line assembly drawing

(f) Assembly drawing of oil and gas pipeline and force measuring platform

Fig. 2 Assembly Diagram of the Physical Simulation Platform for Geological Disasters Involving Oil and Gas Pipeline Collapse

3.2. Experimental Procedure

Using the physical experimental platform designed and constructed as described above, the simulation experiment for the damage of oil and gas pipelines caused by collapsing rocks is carried out according to the following steps:

1) Based on the impact force and energy distribution patterns of collapsing rocks on oil and gas pipelines observed in the field, select appropriate shapes and weights for the heavy objects.

2) The experimental personnel operate the remote control to lower the automatic unhooking device to the ground level. Attach the heavy object selected in step (1) to the electromagnetic suction plate of the automatic unhooking device and lock the braking mechanism.

3) Raise the automatic unhooking device to the designated height.

4) Secure the steel pipe to the force measurement platform using the fixing device. Place the force measurement platform on the ground below the suspended heavy object, ensuring that the center of gravity of the heavy object and the centerline of the steel pipe are aligned in the same vertical plane.

5) Attach strain gauges to the steel pipe and connect the computer, data acquisition card, strain gauges, and force measurement platform using data cables. Turn on the high-speed camera.

6) Debug all testing equipment to ensure safety and reliability.

7) Experimental personnel evacuate to a safe area. After confirming safety, activate the braking mechanism through the remote control to allow the heavy object to hit the steel pipe in a free-fall manner.

8) Repeat steps 1) through 7) to complete physical simulation tests of oil and gas pipelines under different conditions of heavy object shapes, falling heights, soil cover thicknesses, and pipeline types. Record and analyze the data from each group separately to obtain the stress-strain characteristics and macroscopic failure patterns of the oil and gas pipeline when impacted by falling objects from high altitudes.

4. Experimental Results and Analysis

Through experiments, it was found that the oil and gas pipeline sustained varying degrees of damage and deformation under the impact of heavy objects, primarily manifesting as pits and scratches, as shown in Fig. 3.

Fig. 3 Damage and Deformation of Oil and Gas Pipeline after Impact by Collapsing Heavy Objects

The force measurement platform can be used to measure the force exerted on the oil and gas pipeline during the impact of the heavy object, as shown in Fig. 4.

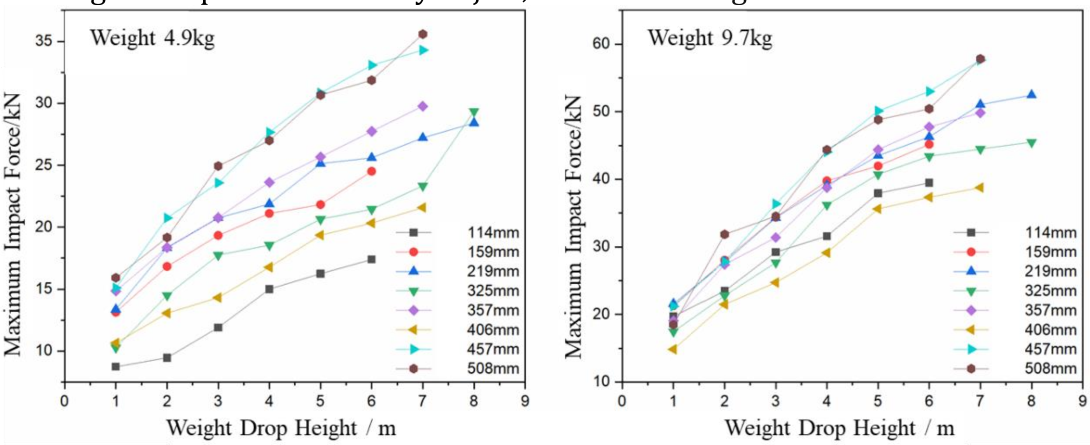


Fig. 4 Force Curve of Oil and Gas Pipeline during Impact by Heavy Object

As shown in the above figure, in the physical model experiments with weights of 4.9kg and 9.7kg, the maximum impact force on the pipeline gradually increases with the increase in falling height. Different pipe diameters also exhibit certain differences and do not show a consistent pattern with changes in pipe diameter, which may be related to the inherent structure of the pipeline. Under the same conditions, steel pipes with diameters of 114mm and 406mm experience less impact force, while those with diameters of 457mm and 508mm experience greater impact force.

5. Conclusion

Through the construction of a simulation platform for the impact of collapsing rocks on long-distance oil and gas pipelines, this paper conducted corresponding experimental research. It was found that the impact force is positively correlated with the mass of the heavy object and the falling height, while it is also affected by the diameter of the pipeline. Under the same conditions, the inherent structure of the steel pipe provides a greater buffering effect against the impact of heavy objects, resulting in better stability. This analysis suggests a close relationship with the strength and deformation characteristics of different pipelines. Therefore, in the transportation of long-distance oil and gas pipelines, the selection of pipelines can be

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made based on geological conditions. In areas with high-intensity collapsing rocks, steel pipes with diameters of 114mm and 406mm can be used, as they experience relatively less impact force, which can play a positive role in long-distance oil and gas transportation under collapsing geological conditions.

References

[1] A.L. Song, G.C. Liang, W.Y. Wang: Current Situation and Development Trend of Oil and Gas Pipelines in the World, Oil & Gas Storage and Transportation, Vol. 25 (2006) No.10, p.1-8.

[2] National Energy Administration Oil and Gas Department: China Natural Gas Development Report. (Petroleum Industry Press, Beijing 2021).

[3] L. Wang, Q.L. Deng, H.J. Yang: Analysis and Evaluation of the Impact of Falling Hazardous Rock Mass on Gas Transmission Pipelines, Hydrogeology & Engineering Geology, Vol. 34 (2007) No.5, p.29-32.

[4] X.L. Ma: Research on the Limit State Design Method of Natural Gas Pipelines under Impact External Loads(MS., Southwest Petroleum University, Chengdu 2017).

[5] H.T. Zhang: Research on Geological Hazard Risk Control of Zhongwu Gas Transmission Pipeline (MS., China University of Petroleum (East China), Qingdao 2015).

[6] S.Z. Zhang: Risk Analysis and Route Selection Methods for Long-Distance Oil and Gas Pipelines (Ph.D., China University of Mining and Technology (Beijing), Beijing 2012).

[7] F. Shang, Y. Fang, K. Huang, S.J. Wu: Stress Analysis of Natural Gas Pipeline Crossing Lancang River under Rockfall Conditions, Chinese Journal of Applied Mechanics, Vol. 34 (2017) No.3, p.483-489.

[8] W. Huang, R. Xie, X.H. Chen: Mechanical Analysis of Buried Oil and Gas Pipelines under Rockfall Impact Loads, Petroleum Machinery, Vol. 47 (2019) No.9, p.138-144.

[9] X.W. Hu, X.F. Mei, Y. Yang: Dynamic Response of Pile-Board Retaining Wall Structure under Rockfall Impact Load, Journal of Engineering Geology, Vol. 27 (2019) No.1, p.123-133.

[10] W.J. Ma, H.S. Li: Experimental Study on Impact Response of Buried Gas Transmission Pipeline under Rockfall, China Measurement & Test, Vol. 44 (2018) No.9, p.23-28.

[11] S.J. Wu: Research on the Impact of Rockfall Collapse on Lancang River Crossing Pipelines and Its Prevention Measures (MS., Southwest Petroleum University, Chengdu 2016).

[12] A.L. Yao, Y.F. Xing, X.G. Zeng: Numerical Simulation Analysis of Dynamic Response of Buried Steel Pipelines under Rolling Stones, Journal of Safety and Environment, Vol. 9 (2019) No.3, p.122-125.