Finite element analysis for impact of rockfall on the buried gas pipeline

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Abstract

Aiming at the problem of rockfall disaster that may faced in long distance oil and gas pipeline engineering, a three-dimensional finite element model of buried pipeline rockfall impact loads is established by using finite element analysis software, and the finite element simulation and hazard analysis of different pressures and different thickness of the buffer layer within the shallow buried pipeline was carried out. The results show that the presence of pressure in pipeline will reduce the carrying capacity, and increasing the depth of the pipeline will increase it. The results in this work have provided a theoretical basis to ensure the safe operation of the buried pipeline and the prediction and prevention potential collapse disaster.

Keywords

Gas pipeline, impact force, finite element, carrying capacity.

1. Introduction

At present, China is in a period of rapid development of long-distance pipeline construction, several major long-distance pipeline project through a large number of geological and geomorphological features, obvious geological disaster prone areas, its safety is always is the first to consider the problems in project construction. The landslide is one of the main geological disasters in the southwest pipeline, due to the collapse occurred not only time is not easy to determine, but the scale of the disaster is not easy to determine. And Once the disaster occurs, not only cause the pipeline deformation, fracture, and massive damage to oil and gas, close the pipeline leak, causing huge economic losses; there will be a fire, explosion and other risks, serious consequences and adverse effects, to life and property, natural environment and social stability. So it is necessary to establish mechanical model of buried oil geological disasters of rockfall under the action of gas pipeline, influence of geological disasters on the pipeline, analyze the mechanical behavior of affected pipelines, finding out the law of various factors influence on the affected pipeline strength and affected pipeline weak links, and on the basis of the governance of landslide disaster and the conception of buried pipeline reinforcement. These studies provide a theoretical basis and scientific means to ensure the safe operation of China's oil and gas pipeline, and it is the premise and basis for the safe operation of buried pipelines [1].

Deformation Mechanism of pipeline under the action of collapse disaster, is a nonlinear contact problems[2].On the theoretical viewpoints, some assumptions and simplifications about the question are necessary, although theoretical formula provides an easy way for engineering applications, but the scope of application and reliability of its conclusions has great limitations. With the development of finite element simulation technology, a more reliable means help us solve these problems that numerical simulation of approaching the problem can maximize the real situation, the mutual combination of theoretical analysis and numerical simulation is available for the higher reliability problems conclusion.

2. Establishing Calculation Model

2.1 Material Models of The Cover Soil and the Rockfall

The selection of soil model is not only to avoid using too complex parameter model, but also can not choose the simple model can not reflect the main characteristics of the soil[3]. In view of the complexity of the deformation behavior of the soil, scientists have put forward many soil models. The work on the stress-strain relation of soil is not strictly required, therefore, the linear elastic model has little effect on the results[4]. In order to improve the efficiency of analog computation, the linear elastic model has been used. In general, the stiffness of the rockfall is much larger than that of cover soil. The rock falls into contact with the soil, causing the vibration of the pipe and soil. Assuming the rockfall is a rigid body, not only can accurately simulate the actual working condition, but also saves the simulation time [5].The basic parameters of the cover soil and the rockfall are shown in Table 1.

Table 1. The basic parameters of the cover soil and the rockfall

Material	Poisson ratio	Density (kg/m3)	Elastic modulus (MPa)
Cover soil	0.4	2000	32.5
Rockfall	0.22	2500	25000

2.2 Material Models of the Steel Pipeline

This paper adopts X70 steel, known from the literatures, the X70 steel is a kind of low carbon micro alloy pipeline steel TMCP, bending with continuous yield characteristics, no obvious yield platform[6]. This steel has very high elongation and high yield strength and tensile strength. The main characteristic of this steel is bilinear kinematic plastic model, namely an ideal elastic-plastic model, which comply with Von Mises yield criterion. The stress - strain relationship of X70 steel shown in Fig.1.

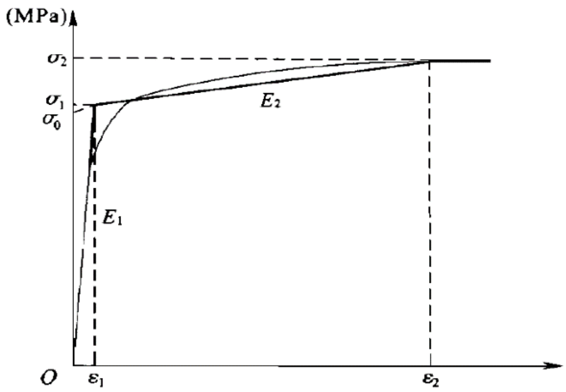

Fig .1 Stress-strain relationship of the steel

The safety evaluation of buried pipeline is carried out based on the pipe stress exceeding the yield strength of pipe and the failure of strength. The physical and mechanical parameters of X70 steel are as follows, poisson ratio of 0.3,density of 7850kg/m3,elastic modulus of 207MPa, σ1 of 503MPa ,E2 of 2246MPa, yield strength of 485~605MPa. The pipeline's calculation parameters are as follows, an outer diameter of 1016mm, wall thickness of 18.4mm,the design pressure of 10MPa.

2.3 Establishment of Finite Element Model

In this study, the SOLID185 element is used to simulate the rock and soil, and the constitutive model of the soil is modeled by the ideal elastic model. The SHELL181 element is used to simulate the pipeline, determine the parameters according to different pipeline, pipe stress-strain relationship by using the bilinear kinematic hardening model, namely the ideal elastic-plastic model, the inflection point stress according to the requirements for material allowable stress, the nonlinear surface to surface contact model to simulate soil pipe interaction, which target the surface unit of the TARGE170 unit, the contact element of the CONTA174 unit, the contact surface behavior as the case definition. For the soil model, the bottom surface were the fixed constraint, and the side were normal constraints. The finite element modeling and the mesh were shown in Fig.2 and Fig.3.

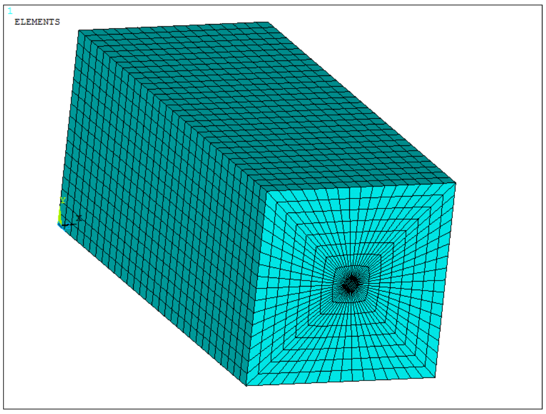

Fig.2 Finite element modeling

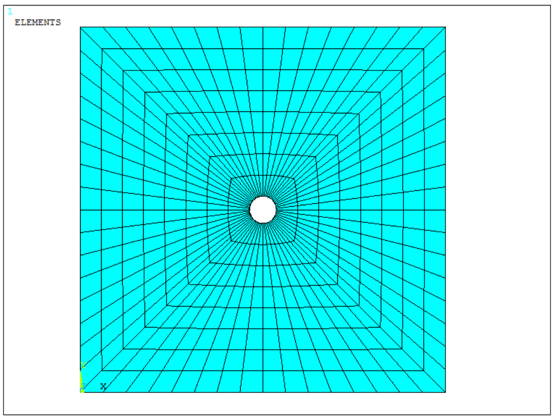

Fig.3 Mesh of buried pipeline

3. Calculation results and analysis

3.1 The influence of the pressure in the pipeline on the calculation results.

The model is 5.016m * 5.016m * 10m, the pipeline buried depth is 2m, the pipe wall thickness is 0.0184m, the pipe diameter is 1.016m, rockfall impact force of 0.5m2 of uniform load falls vertically above the model. The two cases are simulated when there is no internal pressure of pipeline and the inner pressure of pipeline is 10Mpa, and different rockfall impact were applied. The simulation results are shown in Table 2 and Table 3.

Table 2. The calculation results of different impact force with no gas pressure

Rockfall impact force（KN）	Maximum von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
10800	362	0.001762	0.029257
12600	420	0.002045	0.033527
14400	477	0.002323	0.037772
16200	499	0.002597	0.042034
18000	500	0.002986	0.046342

Table 3. The calculation results of different impact force with 10MPa gas pressure

Rockfall impact force（KN）	Maximum von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
5400	408	0.002002	0.015452
7200	465	0.002277	0.019159
10800	497	0.002811	0.029257
12600	498	0.003196	0.032245
14400	499	0.00373	0.037282
16200	500	0.004152	0.041774

From the table we can see clearly that with the increase of impact force, the maximum von Mises stress, maximum strain and maximum displacement of the pipeline are gradually increased. The maximum von Mises stress increases with the increase of rockfall impact force, as shown in Fig4, it can be seen that there is a linear relationship in the elastic range. When the rockfall impact force acting on no gas pipeline is 14400KN, the maximum von Mises pipeline stress is 477MPa, and when the rockfall impact force is 16200KN, the maximum von Mises pipeline stress is 499MPa.According to the linear relationship when estimating the rockfall impact force is 15300KN, the maximum von Mises pipeline stress close to the the minimum yield strength of 485MPa of X70 pipe, so that the partial safety impact to 15300KN pipeline has reached the elastic limit, if continue to increase the rockfall impact force, the pipeline will produce plastic deformation, namely the limit of rockfall impact force under the condition of the pipeline can withstand about 15300KN. When the rockfall impact force acting on pipeline of 10MPa is 5400KN, the maximum von Mises pipeline stress is 408MPa, and when the rockfall impact force is 7200KN, the maximum von Mises pipeline stress is 465MPa.According to the linear relationship when estimating the rockfall impact force is 8000KN, the maximum von Mises pipeline stress close to the the minimum yield strength of 485MPa of X70 pipe,so that the partial safety impact to 8000KN pipeline has reached the elastic limit, the limit of rockfall impact force under the condition of the pipeline can withstand about 8000KN. Fig5 is von Mises stress diagram of pipeline under the condition of no gas transmission.

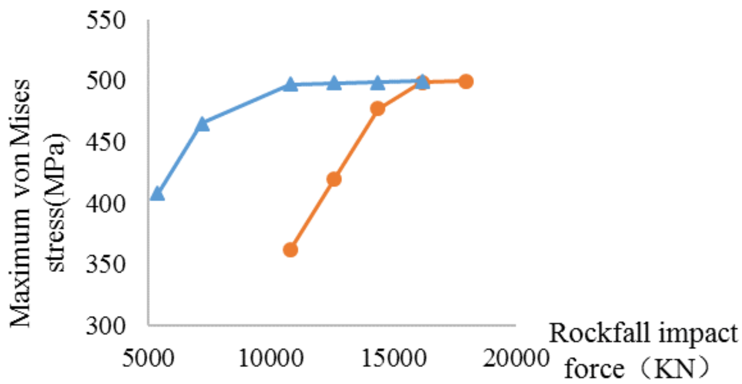

Fig 4. Variation of maximum von Mises stress of pipeline with increasing impact force

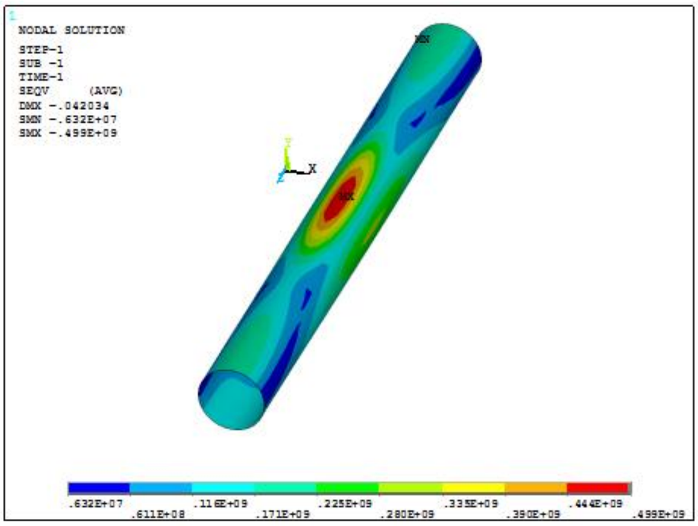

Fig 5. Von Mises stress diagram of pipeline under the condition of no gas transmission

3.2 Influence of Calculation Results on the Depth of Buried Pipeline.

When the depth of pipeline taken at 1m depth and 3m, with 10MPa pipeline pressure, the influence of different forces on the pipeline is calculated.The calculation results shown in Table 4 and Table 5.

Table 4. The calculation results of 1m depth on different magnitudes impact force

Rockfall impact force（KN）	Maximum von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
2700	386	0.001889	0.009374
3600	442	0.002165	0.012514
4500	497	0.002459	0.01581
5400	498	0.002795	0.0019347
6300	499	0.003237	0.022964

Table 5. The calculation results of 3m depth on different magnitudes impact force

Rockfall impact force（KN）	Maximum von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
18000	463	0.002263	0.035026
18900	477	0.002328	0.036656
19800	491	0.002398	0.038346
20700	498	0.002471	0.040074
21600	498	0.002543	0.041861

Can be clearly seen from table 3, table 4 and table 5, with the increase of depth, the bearing capacity of the pipeline has been improved obviously. Depth of 1m, with 10MPa pressure ,when the rockfall impact force acting on pipeline is 3600KN, the maximum von Mises pipeline stress is 442MPa, and when the rockfall impact force is 4500KN, the maximum von Mises pipeline stress is 497MPa.According to the linear relationship when estimating the rockfall impact force is 4200KN, the maximum von Mises pipeline stress close to the the minimum yield strength of 485MPa of X70 pipe,so that the partial safety impact to 4200KN pipeline has reached the elastic limit, the limit of rockfall impact force under the condition of the pipeline can withstand about 4200KN. Depth of 3m, with 10MPa pressure ,when the rockfall impact force acting on pipeline is 18900KN, the maximum von Mises pipeline stress is 477MPa, and when the rockfall impact force is 19800KN, the maximum von Mises pipeline stress is 491MPa.According to the linear relationship when estimating the rockfall impact force is 19300KN, the maximum von Mises pipeline stress close to the the minimum yield strength of 485MPa of X70 pipe,so that the partial safety impact to 19300KN pipeline has reached the elastic limit, the limit of rockfall impact force under the condition of the pipeline can withstand about 19300KN.

4. Conclusion

In this paper, based on the background of landslide and rockfall area, and combining with the actual situation of buried gas pipeline. The finite element software ANSYS is used to simulate and analyze the response of rockfall to different depths:

1) When the pipeline depth is shallow, rockfall impact force affect strength of pipelines apparently, as depth of pipeline increase, the influence of impact force on strength of pipelines gradually decrease.
2) Under the condition of the same rockfall impact force, the bearing capacity of acting on internal pressure of the pipe is lower than that of the pipeline without internal pressure. However, due to the rebound effect of internal pressure of pipeline, the deformation of the pipeline decreases.
3) Can be clearly seen from table 3, table 4 and table 5, when the pipeline buried depth increased from 1m to 2m, the bearing capacity of the pipeline increased from 4200 to 8000, growth rate of 90%; when the pipeline buried depth increased from 2m to 3m, the bearing capacity of the pipeline increased about 140%.
4) The buried depth of pipeline is an important factor in the design of pipeline. The buried depth of pipeline directly affects the investment cost of pipeline. It is possible to ensure the safety of pipeline by increasing the buried depth of the pipeline in the serious geological disaster area.

References

[1] Xiuxing Zhu: The Safety of Buried Oil-Gas Pipelineunder Geological Disaster (MS., China University of Petroleum, China Shandong 2009), p.9.

[2] Hongyuan Jing: Analysis and Numer ieal Simulation on Dynamic Response of Buried Pipeline Caused by Rock fall Impaction (MS., China University of Geosciences, China 2007), p.32.

[3] Zhonghua Xu, Weidong Wang.Selection of Soil Constitutive Models for Numerical Analysis of Deep Excavations in Close Proximity to Sensitive Properties, Rock and Soil Mechanics, Vol. 31 (2010), p.258-362.

[4] Bernhard Pichler, Christian Hellmich, Josef Eberhardsteiner and Herbert A. Mang.Assessment of Protection Systems for Buried Steel Pipelines Endangerged by Rockfall, Computer-Aided Civil and Infrastructure Engineering ,Vol.20(2005),p.333-342.

[5] Yan Wang,Anling Yao,Youlv Li, et al. Impact of rockfall on the gas pipeline with different buried depth[J]. Petroleum Engineering Construction,(2010) No.1,p.4-7.

[6] Weiguo Liu, Anling Yao, Youlv Li, et al. Safety assessment of high pressure buried gas pipeline with crack under impact load,Chinese Journal of Solid Mechanics, Vol. 31 (2010), p. 109-114.