Elastic-Plastic Finite Element Analysis for Zhongwei--guiyang Natural Gas Pipeline Endangered by Collapse

Gengxin Wu[1], Peng Zhang[1], Zhixiang Li [1], Zunhai Ke[1], Guizhi Li[1], Anmin Jiang[2]

[1] School of Civil Engineering and Architecture, Southwest Petroleum University, Chengdu 610500, China

[2] School of Civil Engineering and Architecture, Central South University of Forestry and Technology, Changsha 410004, China.

Abstract

Through the establishment of rockfall impact force is applied to the mechanical model of cover soil of buried pipeline, for the finite element simulation and calculation of different pressures and different depths within the pipeline was carried out. When the buried depth of pipeline is fixed at 2m, with or without internal pressure were simulated; 10MPa pressure in the work, the depth of 1m and 3m in different conditions were simulated. According to the curves between rockfall impact force and maximum Von Mises stress of the pipeline, 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

Impact force, finite element simulation, carrying capacity.

1. Introduction

The distribution of long distance oil and gas pipeline is broad, and it's difficult to avoid geological disasters becausethe geological features along the pipeline is complex. Soil movement and surface deformationthat caused bygeological disasters, resulting in buried pipelines bending, compression, distortion, crack, local buckling and other vandalism[1]. As lifeline engineering, the high-pressure oil and gas pipelines responsible for a major oil and gas resources delivery task, due to the distribution range is very wide, along the regional natural geographical and geological environment is complex and diverse, inevitably threatened and violated various geological disasters. Geological disasters in the event, not only cause the pipe deformation, fracture, and large-scale destruction, resulting in leakage of oil and gas, pipeline shutdown, caused huge economic losses; but there may be a risk of fire, explosion, etc., bringing serious consequences and bad influence to life and property, natural environment and social stability. According to incomplete statistics, the direct economic losses due to geological disasters amounted to 30 billion yuan each year.

Establishing a mechanical analysis model of buried oil and gas pipelines that under the action of geological disasters to study the mechanical response of the affected pipeline, to identify weak links in the affected pipeline and the influence of various factors, and to propose precaution on this. It is the foundation to ensure the buried pipeline secure, thus this study has important application value.

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 thatnumerical 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. Mechanics Model and Finite Element Model

2.1 Material Models of the Cover Soil and the Rockfall.

So far, scientists have proposed hundreds of soil model, which is in view of the complexity of the deformation behavior of the soil [3]. This work on the stress-strain relation of soil is not strictly required, therefore the use of linear elastic model is very small effect on the study results [4].In order to improve computational efficiency, the linear elastic model has been adopted.

The stiffness of the collapse masses is much larger than that of cover soil, and the assumption that the soil is a rigid body can not only accurately simulate the actual situation, but also greatly save the finite element simulation software.

The basic parameters of the two materials are shown in Table 1.

Table 1 The basic parameters ofthe cover soil and the rockfall

Material	Poisson ratio	Density (kg/m^3)	Elastic modulus (MPa)
Covel soil	0.4	2000	32.5
Rockfall	0.22	2500	25000

2.2 Constitutive Relation of X80 Pipeline Steel.

X80 steel is used in pipeline of zhongwei--guiyang, such grades of steel not only with high yield strength and tensile strength, but with good plasticity [5].Thissteel is characterized by bilinear kinematic plastic model, namely an ideal elastic-plastic model, which stress - strain relationship shown in Fig.1[6]. And the model comply with Von Mises yield criterion.

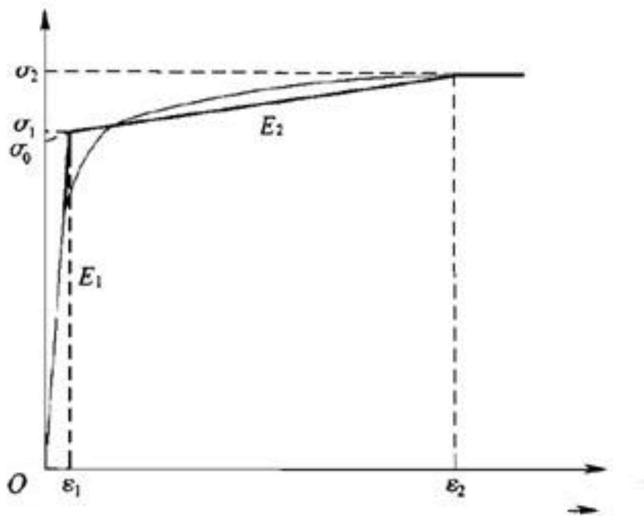

Fig .1 Stress-strain relationship of the steel

For the pipeline failure of judgment, when the tube stress exceeds the yield strength of the pipe material, the occurrence of strength failure, namely that the pipeline failure. Physical and mechanical parameters of the steel shows in Table 2.The pipeline's calculation parameters are as follows, an outer diameter of 1016mm, wall thickness of 15.3mm, the design pressure of 10MPa.

Table 2 Physical and mechanical parameters of the steel

Steel	Poisson ratio	Density (kg/m^3)	Elastic modulus (MPa)	σ_1 (MPa)	E_2 (MPa)	Yield strength (MPa)
X80	0.3	7850	207	544	6210	555~675

2.3 .Finite element modeling.

Adopting element SOLID185 and element SHELL181,the soil and the pipeline were simulated, andnonlinear surface - face contact model to simulate pipe - soil interaction, in which the target surface unit uses TARGE170, the contact surface unit with CONTA174.A mixing meshing method has been used in this paper. For the soil model, the bottom surface were the fixed constraint, and the side were normal constraints. The finite element modeling and the mesh nearby buried pipeline were shown in Fig.2 and Fig.3

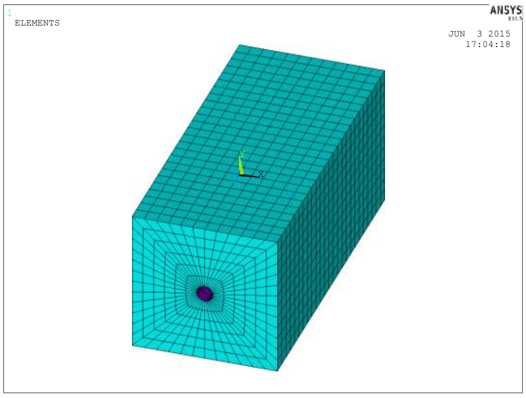

Fig.2 Finite element modeling

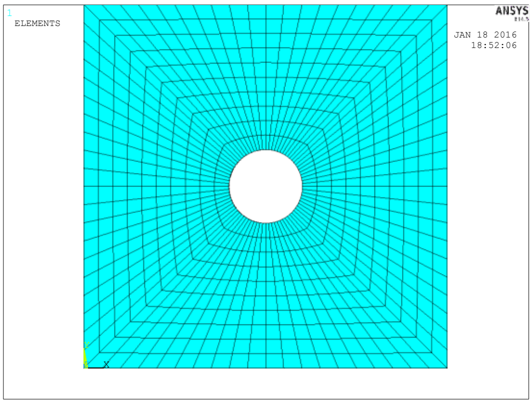

Fig.3 mesh nearby buried pipeline

3. Results and Discussion Based on Finite Element Calculation

3.1 The Impact on the Results of Pressure in the Pipeline.

Model is taken to 5.016m × 5.016m × 10m, pipeline depth is 2m, rockfall impact force of 0.5m^2 of uniform load which acting on the upright top position of the model. No gas pipeline and gas pressure of 10MPa state were simulated, respectively acting on rockfall impact of different magnitudes, the calculation results are shown in Table 3 and Table 4.

Table 3 The calculation results of no gas pipeline on different magnitudes impact force

Rockfall impact force(KN)	Maximum Von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
4500	163	0.000796	0.015172
9000	320	0.001555	0.026879
13500	472	0.002297	0.038463
18000	542	0.003107	0.005045
22500	549	0.004641	0.062265
27000	561	0.006596	0.075408

Table4 The calculation results of 10MPa gas pressure pipeline on different magnitudes impact force

rockfall impact force(KN)	Maximum Von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
4500	427	0.002097	0.014082
5400	456	0.002235	0.016438
6300	481	0.002396	0.01845
7200	513	0.002514	0.021122
8100	537	0.002656	0.023449
9000	538	0.002809	0.025816

It can be clearly seen from the table, with the increase in rockfall impact, pipe maximum Von Mises stress, maximum strain and maximum displacement are gradually increasing.Fig.5 is the relationship between rockfall impact force and Von Mises stress, it can be seen a linear relationship in the elastic range. When 22500KN rockfall impact force acting on no gas pipeline, the maximum Von Mises stress is 549MPa, close to the X80 pipe minimum yield strength (555MPa), therefore impact force reaches 22500KN pipeline has reached the elastic limit state, if it continues to increase, the pipeline will produce plastic deformation, that pipeline can withstand the extreme rockfall impact force of about 22500KN.When pipeline of 10MPa bearing 8100KNrockfall impact force, the maximum Von Mises stress in it is 537MPa, already approaching the yield strength X80 steel, and then continue to increase the force of the slow growth of stress, butstrain and vertical displacement continued to rapid increase, and therefore can be the yield limit of the pipeline under this condition, partial safely deems 8000KN is the elastic limit state.

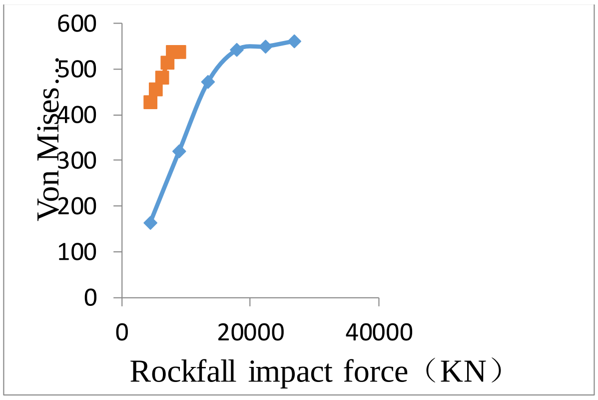

Fig.5 Relationship between rockfall impact force and Von Mises stress of pressure Von Mises stress graph of no gas pipeline in Fig.6.

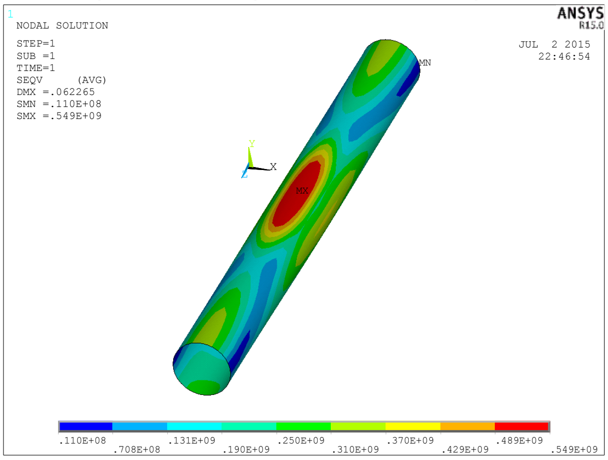

Fig.6 Von Mises stress graph of no gas pipeline

3.2 The Impact on the Results of Depth ofthe Pipeline.

Depth taken at 1m depth and 3m, with 10MPa pipeline pressure, which bearing rockfall impact force, the calculation results shown in Table 5 and Table 6:

Table5 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)
1800	377	0.00185	0.006627
2700	429	0.002102	0.009919
3600	485	0.002373	0.001332
4500	538	0.002672	0.016951
5400	540	0.003006	0.020785
6300	542	0.003562	0.024322

Table4 The calculation results of 3m depth pipeline on different magnitudes impact force

rockfall impact force(KN)	Maximum Von Mises stress(MPa)	Maximum strain	Maximum vertical displacement(m)
17100	488	0.002386	0.034334
18000	502	0.002454	0.035976
18900	515	0.002517	0.037722
19800	530	0.002588	0.039527
20700	538	0.002659	0.041456
21600	539	0.002731	0.043142

The data in the scatter plot(Fig.7), can be clearly seen, as the depth increases, the carrying capacity of the pipeline has been significantly improved. Depth of1m, with 10MPa pressure ,when the rockfall impact force reach 4500KN, the maximum Von Mises stress in the pipeline is 538MPa, already approaching the yield strength of X80 steel, and then continued to increase impact when the stress of slow growth, but the strain and vertical displacement continues to increase rapidly, and therefore can be the yield limit under this condition, partial safely 4500KN is the elastic limit .Depth of 3m, when bearing 20700KN rockfall impact force, the maximum Von Mises stress in the pipeline is 538MPa, is also close to the yield strength. As the 1m depth, this is the yield limit under 3m depth and 10MPa pressure, partial safely assume that the impact force reached 20000KN when pipeline has reached the elastic limit state. That is such a pipeline can bearing the extreme conditions rockfall impact force of about 20000KN.

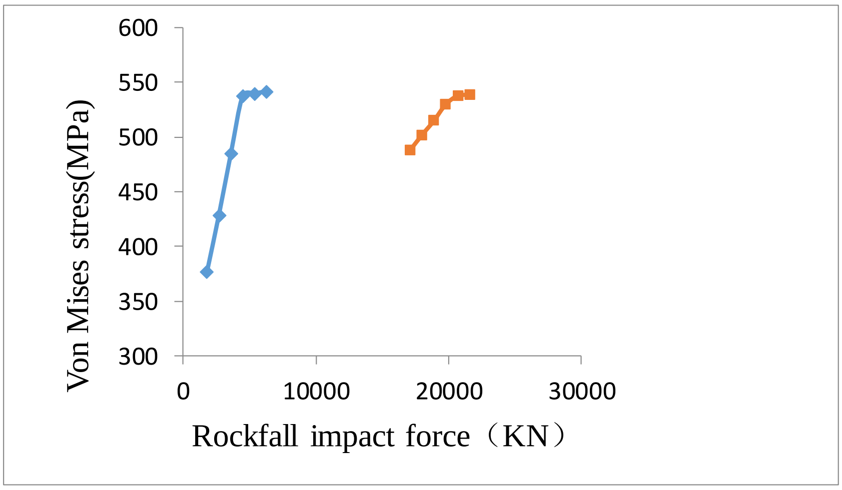

Fig.7 Relationship between rockfall impact force and Von Mises stress of depth

4. Conclusion

By the corresponding simplified forms of mechanical model, using the finite element software analyzing the calculation results, the following conclusions were obtained:

(1) Maximum Von Mises stress and rockfall impact substantially was linear relationship in the range of elastic deformation, which verify the correctness of the material model of steel used in this paper;

(2) Under the same rockfall impact force, the pipeline carrying capacity is relatively weak which with internal pressure; however, to the rebound effect of internal pressure, the deformation decrease;

(3) Compare Table 4, Table 5 and Table 6, it can be seen from depth of 1m to 2m, the carrying capacity of the pipeline increased from 4500KN to8000KN, increased by about 80%; when the depth from 2m to 3m, carrying capacity of the pipeline from 8000KN to 20000KN, increasedby about 150%. It can be seen a direct impact on bearing capacity of the pipeline depth, which depth deeper pipeline

carrying capacity stronger and, the carrying capacity of the pipeline will be doubled to increase with depth deeper.

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