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Numerical simulation on the damage of buried thermal-pipeline under seismic loading based on thermal-mechanical coupling

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Abstract

The thermal-mechanical coupling effect is one of important factors in construction engineering, which will cause the buried thermal-pipeline to damage. So a three-dimensional finite element model of damage of the buried pipeline is established based on ADINA-TMC, which considers thermal-mechanical coupling and seismic loading simultaneously. In this model, seismic loads and faults movement are defined. According to the numerical results, stresses and strains under gravity, seismic loading, and temperature load are compared, which provides theoretical method for failure analysis of buried thermal-pipeline.

Keywords: buried thermal-pipeline; thermal-mechanical coupling; ADINA; temperature load; construction engineering; seismic loading

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1. Introduction

Buried thermal-pipeline is used widely in urban thermal engineering because of its many advantages, such as fast construction, ground space saving, good insulation, and so on. As an important part of underground safety line, buried thermal-pipeline is destroyed easily under seismic loading. Now, many researchers at home and abroad have investigated mechanism on damage of buried pipeline. Pipeline is regarded as elastic-plastic material, H. Grebner (1984) predicted leakage area of pressure pipe and deduced the relationship between pressure and leakage area [1]. J. Palmer et al. (1998) used the finite element method to investigate lateral bending because of thermal expansion [2]. D. H. Lee et al. (2009) obtained seismic time curve of buried pipeline conveying natural gas, which considered the type of pipe, geological conditions, buried depth of pipe, input type of seismic loading, and so on. He analyzed relative displacement in the axial and horizontal direction [3]. A. Amirat et al. (2006) investigated the distribution of residual stress of large diameter pipeline under corrosive environment [4]. L.M.Jia et al. (2010) analyzed the thermal-mechanical

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coupling on damage of wellbore casing, and established a three-dimensional finite element model of casing damage under temperature, gravity and stratum movement [5].

In a word, there are shortcomings in the researches on the damage of buried thermal-pipeline. Finite element method is used widely in analyzing damage of buried pipeline. In this paper, a finite element software-ADINA is used to establish a three-dimensional finite element model, which can analyze the damage of buried thermal-pipeline. In this model, many coupling influences are considered comprehensively, such as seismic loading and fault movement restriction. According to numerical results, stress and strain of buried thermal-pipeline are compared under different loadings, which can provide theoretical bases for damage analysis and safety evaluation of buried thermal-pipeline.

2. Thermal-mechanical coupling model

ADINA is applied to establish structural model and thermal model respectively. Then the coupling calculation is carried on to analyze thermal-mechanical coupling effect on the damage of buried pipeline.

2.1. Structural model

Structural model is established in ADINA-Structure. Buried pipeline is selected in the geometrical model, and soil body is simplified as a cuboid which is established in Parasolid method. So the geometrical model of pipeline is achieved by Boolean operation, soil cutting and Native method. The restriction of model is determined by fault type. Faults movement can be taken as the movement of two layers, which one is static and the other is relatively moving. Then the restriction is applied on the static layer. Considered the actual deformation of pipeline, restriction is applied on one end and internal wall of the pipeline. There are gravity and horizontal seismic loading on the model. Based on ADINA, different loadings can be defined by different time functions. Time function of gravity is constant value, and horizontal seismic loading is shown as Fig. 1. Furthermore, free grid of 3D solid and 8 nodes is adopted in pipeline, 3D solid and 4 nodes is adopted in soil body, which ensures the consistency in dividing unit of model. Structural model is obtained as Fig.2 by dividing grid.

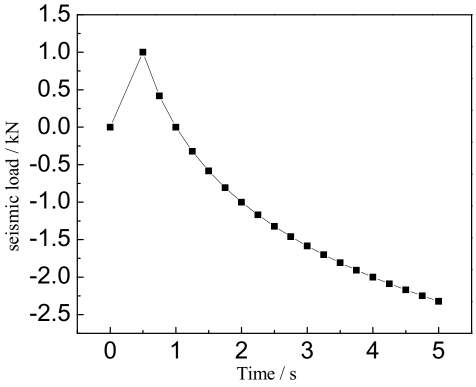

Fig.1 Time function of horizontal seismic loading

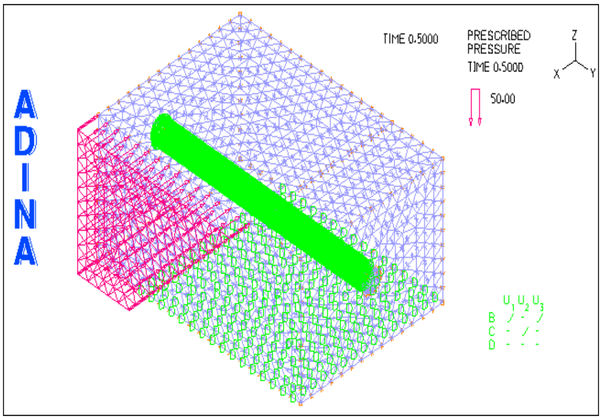

Fig.2 Structural model

2.2. Thermal model

Copy F.E.Model from ADINA Structures to ADINA Thermal Model. Then define initial condition and load. Initial temperature is set to 20℃, and is applied on the pipeline and surrounding soil. Internal fluid is regarded as heat source. Temperature load shown as Fig.3 is applied on inner wall of pipeline. In thermal model, 8 nodes and three-dimensional heat conduction unit is adopted in pipeline, and 4 nodes unit in soil body. So the final thermal model is obtained as Fig.4.

Based on the two models above, coupling solution can be done.

2.3. Model parameters selection

Size of soil body is 7×10×5m3. Thickness of pipeline wall is 0.016m, and diameter is 0.8m. Parameters of materials are selected as table 1.

In ADINA-Structure, there are static and dynamic loads. Static load includes gravity, and dynamic load includes seismic load. In ADINA-Thermal, load is temperature load which is selected as 1℃×time function.

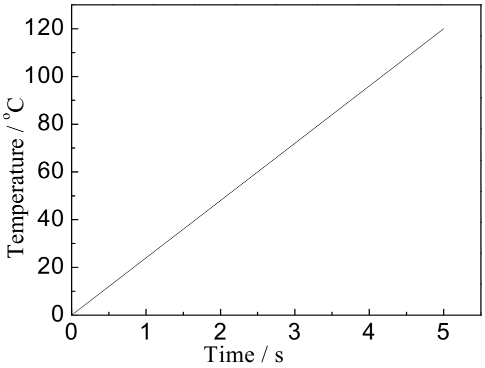

Fig.3 Time function of temperature loading

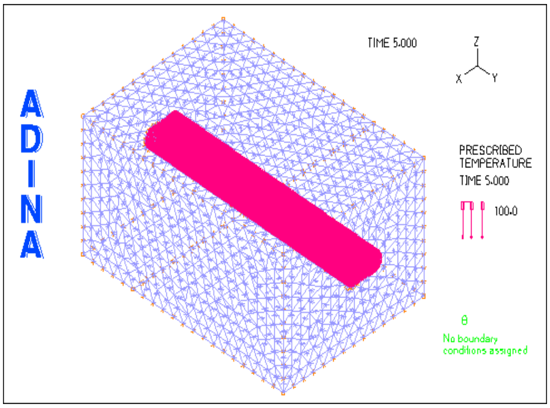

Fig.4 Thermal model

Table1. Material parameters

Material type	Elastic modulus /MPa	Poisson's ratio	Density（g/m^3）	Coefficient of thermal expansion
Pipeline	210000	0.3	7800	1.2
soil	5700	0.42	1880	0.45

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3. Numerical calculation and results analysis

By calculating above model, distributions of stress and strain of pipeline are obtained. So the damage of pipeline can be analyzed for one point or the whole pipeline.

3.1. The influence of temperature under gravity

Fig.5-7 show time curves of effective stress, axial strain and circumferential strain under gravity only. The ratio of diameter and thickness is 0.02. And the influence of temperature is considered or not.

It can be seen that stress and strain are nearly unchangeable without temperature. When the influence of temperature is considered, stress and strain will increase with the increase of temperature. Because the initial temperature is zero at 0~0.5s, gravity plays a role. Stress decreases obviously firstly, then it increases with the increase of temperature. So the damage in the axial and circumferential direction will increase with the increase of temperature.

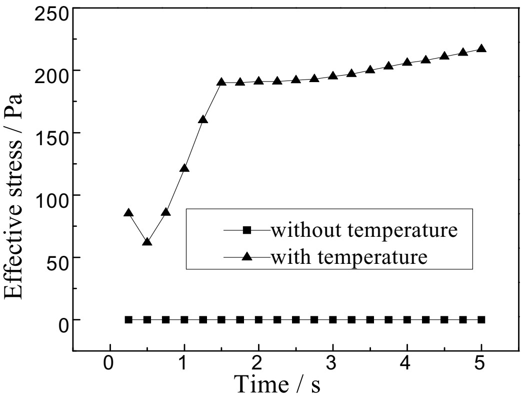

Fig.5 Time curve of effective stress

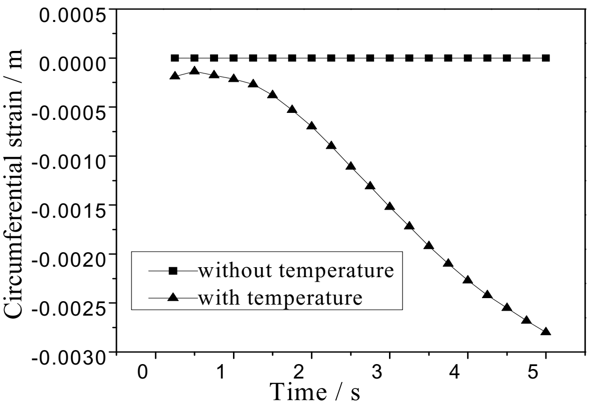

Fig.6 Time curve of circumferential strain

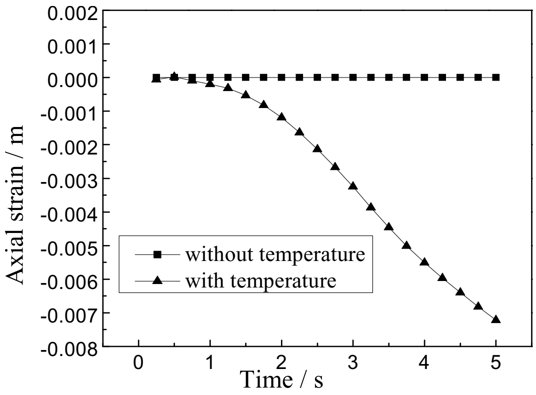

Fig.7 Time curve of axial strain

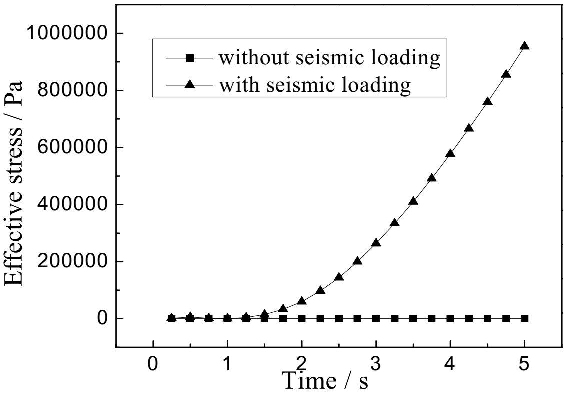

Fig.8 Time curve of effective stress

3.2. The influence of seismic loading

Fig.8-10 are time curves of effective stress, axial strain and circumferential strain with the ratio of diameter and thickness 0.02. The effects of gravity and temperature are considered, with and without seismic load are analyzed.

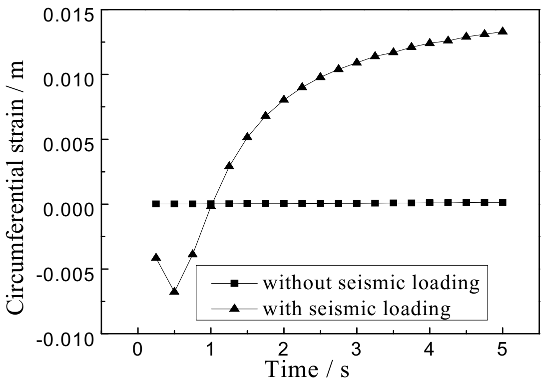

Fig.9 Time curve of circumferential strain

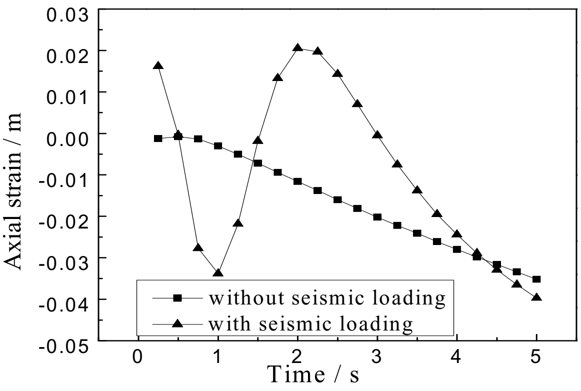

Fig.10 Time curve of axial strain

It can be seen that the influence of temperature on stress and circumferential strain is little without seismic loading, axial strain increases with the increase of temperature. Under seismic loading, effective stress and circumferential strain increase obviously, but axial strain changes consistently with the seismic loading. So, if the seismic loading is considered, circumferential damage increases, and axial damage changes consistently with seismic loading.

3.3. The influence of temperature under gravity and seismic loading

Fig.11 is time curve of axial strain with the temperature under gravity and seismic loading. It can be seen that axial deformation under seismic loading is offset with the temperature from 0℃ to 100℃ because of thermal expansion. So, under gravity and seismic loading, temperature affects the axial strain, and makes the axial damage decrease.

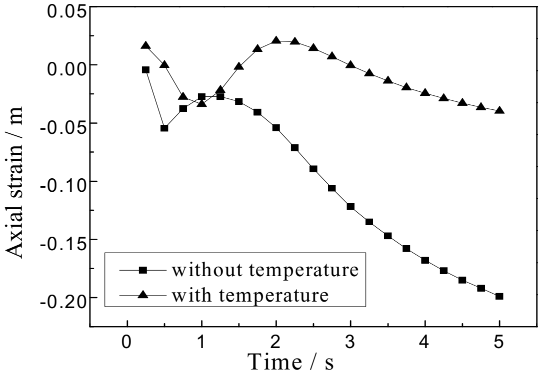

Fig.11 Time curve of axial strain

4. Conclusions

A three-dimensional finite element model of buried thermal-pipeline for construction engineering is established above. Some conclusions are obtained by analyzing the damage of buried thermal-pipeline under thermal-mechanical coupling:

(1) Under gravity, deformation of pipeline is little without temperature; stress and strain will increase obviously with the increase of temperature, especially the damage in the circumferential and axial direction.

(2) If no seismic loading, the influence of temperature on stress and strain of pipeline is little; when with seismic loading, the influence of temperature on stress and strain is obvious, which makes the circumferential damage increase and the tendency of axial damage is the same as seismic loading.

(3) Under gravity and seismic loading, temperature affects axial strain mainly. Axial damage decreases with the increase of temperature, which is verified in actual engineering.

So, the effect of thermal-mechanical coupling under seismic loading should not be ignored in buried thermal-pipeline. These results can provide certain theoretical bases for failure analysis and safety evaluation of buried thermal-pipeline.

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Acknowledgements

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