NUMERICAL STUDY ON DAMAGE TO BURIED OIL PIPELINE UNDER LARGE FAULT DISPLACEMENT

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SUMMARY

In this paper, nonlinear finite element method was applied to study the rupture behavior of buried oil pipeline which had been severely damaged on the Ms 8.1 earthquake near Qinghai-Xinjiang border. The basic information of specificities of pipeline, material property, ground surface rupture and site condition were collected, especially the damage detail of the oil pipeline. Then, numerical analysis was performed in order to find out the main features of damage to the pipeline. Calculating results showed that the position of the Z-shape buckling deformation of the pipeline was in accordance with the post earthquake investigation. Parameter study on pipe material property, soil site stiffness, pipe diameter and fault dip were also conducted. Some seismic countermeasures were recommended according to numerical simulation.

INTRODUCTION

The ground surface rupture with a length up to 400 kilometers was observed in Ms 8.1 earthquake near Qinghai-Xinjiang border. An oil pipeline was broken at where it cross the Qing-Zang Road and pass through the ground surface rupture, pipeline located other places maintained well. The information about specificities of oil pipeline, pipe material property, ground surface rupture and site condition were collected during post earthquake investigation, especially the damage detail of the pipeline, see table 1.

Table 1 ground surface rupture and damage state of the oil pipeline

Earthquake	Ms 8.1 earthquake near Qinghai-Xinjiang border
Fault type	Strike-slip with reverse slip
Displacements of ground surface rupture	Horizontal: 0.6m¡«3.5m, Vertical: 0.0m¡«0.8m
Pipe	Oil pipeline with $\varphi=17cm$, $t=8.5mm$
Angel β of pipe and surface rupture	180^0
Soil condition	Plateau frozen soil
Damage state of pipe	Z-shape buckling deformation 3m right to the road

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In order to understand the main features of the damage of the pipeline, as well as searching for seismic countermeasures of pipeline crossing fault, founded by China Earthquake Administration, the numerical study on damage to buried oil pipeline subject to large fault displacement was carried out by a research group in IEM. Based on information of post earthquake investigation, a 3-D pipe-soil interaction model was constructed. Nonlinear finite element method was applied to study the rupture behavior of the pipeline. The Z-shape buckling deformation of the pipeline was reproduced and the position of the buckling was in accordance with the post earthquake investigation. Then, attention was paid to parameters study such as pipe material properties, site soil stiffness, etc. These parameters have important effects on response of pipeline subjected to ground surface rupture. Some seismic countermeasures of fault crossing pipeline were checked and suggested by case studies.

GROUND SURFACE RUPTURE AND DAMAGE STATE OF PIPELINE

The ground surface rupture of Ms 8.1 earthquake traversed a road near Kunlun Mountain pass, the type of the fault is strike-slip with reverse slip. The maximum of horizontal displacement is about 3.5m, and the maximum vertical displacement is about 0.8m. Fig. 1 is sketch of the ground surface rupture. Fig. 2 shows the distribution of horizontal fault displacement on site of the pipeline. You can find that the fault displacement is larger in right, medium in left and smaller near the road.

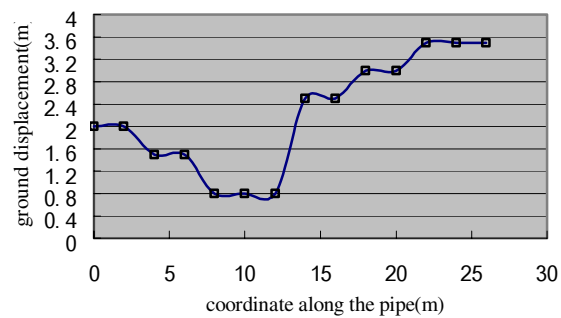Fig. 1 Ground surface rupture   Fig. 2 Distribution of horizontal fault displacement

An oil pipeline passed through the road at the same place as the ground surface rupture. Fig. 3 shows the relative position of road, pipeline and the rupture. The pipeline can not withstand the action of fault displacement, it was definitely broken. Fig. 4 and Fig. 5 are photos of damage state of the pipeline after earthquake.
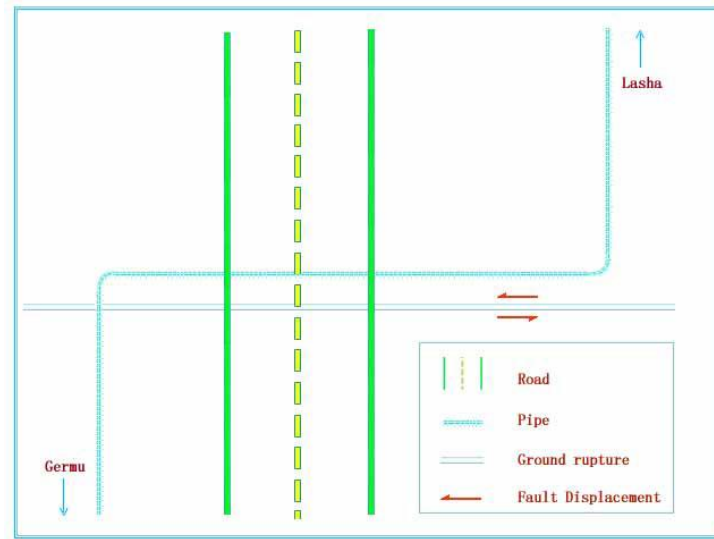
Fig. 3 Relative position of pipe, road and the rupture

Fig. 4 Pipe damage state(a)

Fig. 5 Pipe damage state(b)

NUMERICAL STUDY ON DAMAGE OF THE PIPELINE

Based on the construction achieve of the pipeline engineering, a 3-D shell-spring finite element model was built to simulate the interaction of site soil and pipeline under fault displacement. The model consists of pipeline crossing the road and two 10m length pipeline parallel to the road. The pipe is modeled as shell element that local buckling and large deformation can be considered. Site soil is modeled as soil spring element. The two-linear strain-stress model is applied in the analysis. ANSYS was used to perform the numerical analysis. The damage state of the pipeline model was obtained with the same displacement input as post earthquake investigation. The pipeline suffered a buckling damage. The position of Z-shape buckling deformation was in accordance with the actuality. It is clear that the analysis method is practicable. Fig. 6 shows the strain distribution and deformation of pipeline model, Fig. 7 is Z-shape buckling deformation of the pipe model.
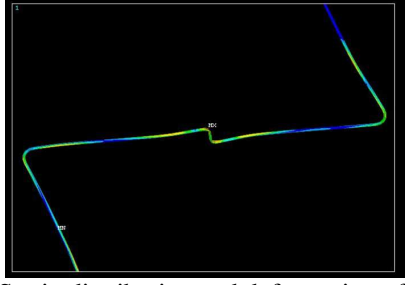

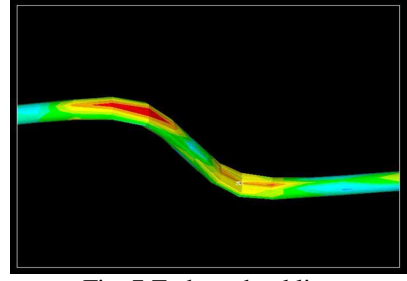Fig. 6 Strain distribution and deformation of pipeline   Fig. 7 Z-shape buckling

PARAMETER STUDY

By numerical simulation, we studied the pipe and the site soil characteristics' influence on response of pipeline under fault displacement. The main parameters include pipe diameter, steel property, soil spring stiffness and fault dip. The followings are some results and discussions.

Pipe material property
Based on the model above, a set of pipe material properties are proposed in the analysis. The maximum strain of the pipe with different initial elasticity modulus and same yielding point stress are shown in Fig. 8, it is obvious that the pipe strain becomes smaller when the initial elasticity modulus become bigger which means higher capacity.
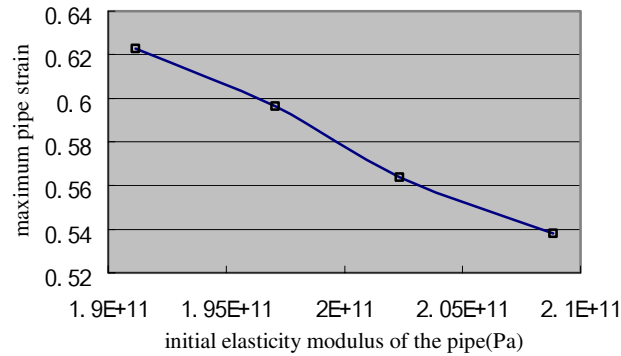

Fig. 8 Pipe strain with variable pipe initial elasticity modulus

Site Soil stiffness
Soil spring stiffness is decided by the size of pipe element and site soil properties. Large pipe element and site soil with higher stiffness leads to larger soil spring stiffness. The soil stiffness is related to its initial elasticity modulus and yielding capacity. Pipe strain calculating results with different elasticity modulus are compared, as shown in Fig. 9, while soil elasticity modulus increases, the strain responses of pipe elements goes up, it is clear that softer site soil is better for pipe crossing fault.
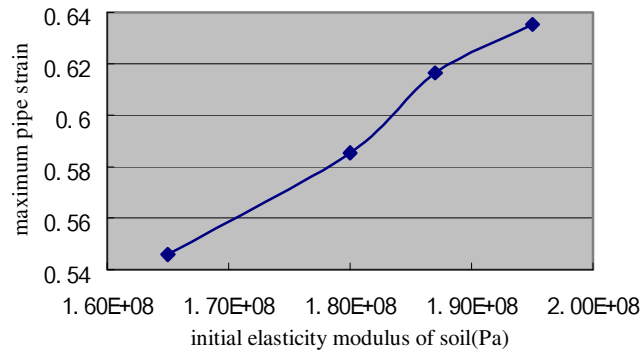
Fig. 9 Pipe strain with different initial elasticity modulus of soil

Pipe diameter

For pipeline with different diameter of 150mm, 170mm, 300mm and 400mm, other parameters remain the same, the pipe elements' maximum strain response is 0.8870, 0.8424, 0.6638 and 0.1439 respectively, the analysis shows that larger diameter pipelines can resist larger fault displacement.
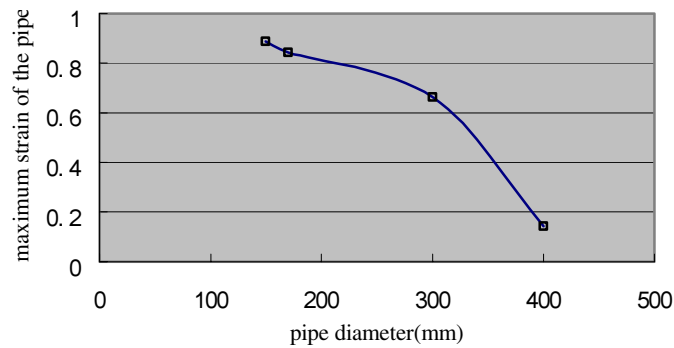

Fig. 10 Pipe strain with different pipe diameter

Fault dip

Under the action of same normal-slip fault displacement with different fault dip of 90 degree, 60 degree, 45 degree and 30 degree, the maximum pipe element strain is 0.029, 0.0511, 0.0782 and 0.167 respectively. It means that gentle dip leads to larger pipe element strain. As to reverse fault with fault dip of 45 degree, 60 degree and 90 degree, the maximum pipe element strain is 0.089, 0.0378 and 0.029 respectively, it also means that gentle dip results in larger pipe element strain. From the study, it implies that fault dip of 90 degree is not the most dangerous case under certain site conditions.
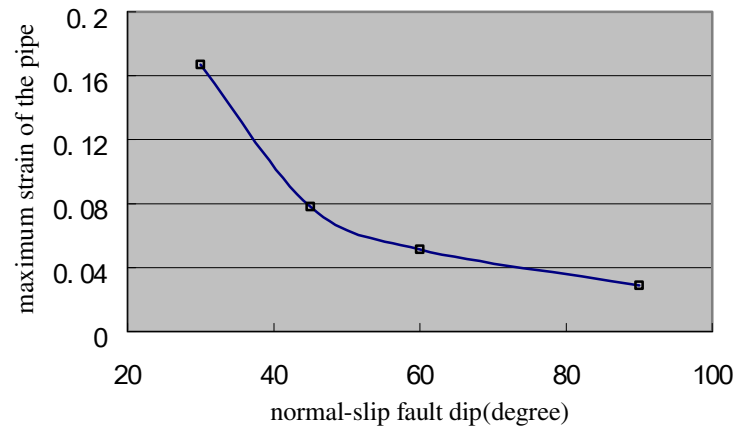
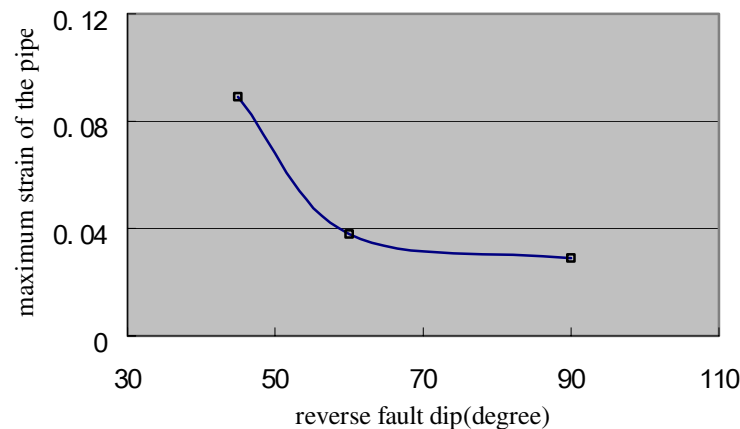Fig. 11 Pipe strain with different dip of normal-slip fault

Fig. 12 Pipe strain with different dip of reverse fault

CONCLUSIONS

Nonlinear finite element method was applied to study the damage of buried pipeline which had been broken on the Ms 8.1 earthquake near Qinghai-Xinjiang border. Z-shape buckling deformation was reproduced and the position of the buckling was in accordance with the post earthquake investigation. Parameter study results shown that the following seismic countermeasures could be recommended for pipeline crossing fault. a) try to use pipeline with larger diameter and thicker wall, b) reducing the restrain of the pipeline caused by site soil, better to bury the pipe with backfill which is softer, c) using pipe with high strength, d) it is better to adjust the direction of the pipe to the fault so as to avoid the pipe being in compressive state in future earthquake.

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