Safety analysis of gas pipeline under vehicle load

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Abstract. With the rapid development of the economy, construction has been carried out throughout the country. Natural gas pipe network is widely distributed, so construction vehicles driving on the ground with buried gas pipelines often exert pressure on the pipelines. If the pipelines are not buried deep enough, the pipeline material strength is poor or the construction quality is not qualified, the pipelines may be deformed or even broken when they are under high pressure. In this paper, the influence of excavator and heavy truck load on gas pipeline is analyzed by using finite element software. The results show that the construction vehicle propagates pressure load through the soil, which causes the local concentrated pressure above the pipeline and causes the pipeline deformation. In view of the safety hidden danger caused by the third party construction vehicles, this paper also gives some Suggestions and measures.

1. Introduction
Pipeline transportation has become one of the five transportation systems including railway, highway, water transportation and air transportation. In recent years, increasing the scale of natural gas pipe network construction, by the end of 2018, China's run long distance natural gas pipeline total mileage reached 76000 kilometers, west to east gas pipeline system, the Shanxi-Beijing system, southwest of Sichuan to east gas, pipeline system on the basis of national gas supply network, gas pipeline construction is developing in the direction of the high pressure and large diameter [1].

Most of the long-distance natural gas pipelines are laid in the suburbs and fields where human activities are less. However, with the rapid economic development, the country has strengthened the construction of urbanization, so the surrounding environment of the natural gas pipelines has undergone great changes [2]. Excavations are under way in many areas, and many construction vehicles now pass or stop frequently to work on gas pipelines that would otherwise be used by few vehicles. In the construction process, heavy vehicles will inevitably crush the pipeline, seriously jeopardizing the safe operation of the pipeline.

2. Finite element model
2.1. Model building
The influence of vehicle load on pipeline under different conditions can be effectively analyzed by numerical calculation. The finite element software ANSYS is used in this study.

The X70 steel widely used at present was selected as the research object for the pipeline, and mohr-coulomb model was selected, whose material parameters are shown in table 1.
Table 1. X70 steel material parameters.

| Density (kg/m³) | Yield strength (MPa) | Tensile strength (MPa) | Elastic Modulus (GPa) | Poisson ratio |
|-----------------|----------------------|------------------------|-----------------------|--------------|
| 7850            | 485                  | 570                    | 209                   | 0.3          |

The Drucker-Prager model is used to simulate soil properties because the soil has the property that the compressive yield strength is much greater than the tensile yield strength [3]. In this study, two groups of soil along the natural gas pipeline were excavated as research objects. The soil in group A was medium hardness clay and that in group B was sandy clay. The parameters obtained by analysis are shown in table 2.

Table 2. The soil parameters.

| Soil    | Density (kg/m³) | Elastic Modulus (MPa) | Cohesion (Pa) | The angle of internal friction (degree) | Poisson ratio |
|---------|-----------------|-----------------------|---------------|----------------------------------------|--------------|
| Group A | 1750            | 8.1                   | 8000          | 20                                     | 0.35         |
| Group B | 1600            | 15.0                  | 6000          | 25                                     | 0.3          |

It is assumed that the soil mass is an isotropic and homogeneous continuum with a dimension of 12m long, 5m wide and 4m deep. The buried depth of the pipeline is 1.2m. The pipe diameter is 0.810m, the wall thickness is 0.012m, and the internal pressure is 6MPa. At the same time, a contact with a friction coefficient of 0.4 was established between the soil and the pipeline.

2.2. Mesh generation

In the calculation of the model, in order to improve the calculation accuracy as much as possible and reduce the calculation amount, the tetrahedral element is used for mesh division in this study, among which solid186 element is used for pipe and soil, and contact174 element is used for contact simulation. The finite element model of soil and gas pipeline is shown in figure 1.

![Figure 1. Finite element model of soil and pipeline.](image)

2.3. Apply constraints and loads

A vertical constraint is set at the bottom of the soil, a symmetrical constraint is set in the left, right, front and rear directions, and an axial constraint is set at both ends of the gas transmission pipeline to limit the displacement in the axial direction of the pipeline [4]. Meanwhile, the internal pressure is set to 6MPa. This paper mainly studies the load influence of construction vehicles, so according to the actual situation, the finite element analysis of excavator roller pipe and heavy truck roller pipe is carried out respectively.
2.4. Validation of finite element model
The simulation results are often different from the field measured results, but the regularity is consistent. The main reason for the difference is that homogeneous soil layer is used in numerical calculation to simulate the actual heterogeneous soil layer [5]. In order to verify the accuracy of the finite element model, the existing experimental data were used for verification. In the model containing only soil, the rolling load of a 13.5t wheeled excavator was applied to calculate the stress values at 1.0m, 1.2m and 1.5m directly below the crushing of the excavator. The comparison of the results is shown in table 3. As can be seen from table 3, the deviation between the two is less than 8%, which is within the acceptable range of engineering error. Therefore, the finite element model can accurately simulate the displacement of the gas pipeline under the rolling action of construction vehicles.

| Buried depth(m) | Simulated value(MPa) | Measured value(MPa) | Deviation(%) |
|-----------------|----------------------|---------------------|--------------|
| 1.0             | 0.0812               | 0.0772              | 5.18         |
| 1.2             | 0.0685               | 0.0669              | 2.39         |
| 1.5             | 0.0532               | 0.0493              | 7.91         |

3. Excavator crushes pipeline
In the process of excavation and construction in the field, due to the lack of obvious pipeline identification and the lack of knowledge of the construction personnel, excavators often work in the vicinity of the pipeline without being reported, causing rolling damage to the pipeline.

3.1. The application of an excavator load
Due to strict control and obvious targets, large crawler excavators often get effective early warning, so only small and medium-sized wheeled excavators are considered. In most cases, the body of the excavator is not shifted or only shifted a little, and the influence of its load on the pipeline changes slowly. Therefore, it is simulated as a static load, and the simulation results of various soil conditions are also considered [6].

For the convenience of mechanical analysis, it is generally assumed that the rolling load of vehicles is evenly distributed over the rectangular loading area. According to a medium-sized four-wheel excavator, the vehicle mass is 13.5t, the grounding pressure is 0.31MPa, and the loading rectangular area is 0.2m × 0.546m.

3.2. Analysis of calculation results
The finite element model was calculated respectively under the soil environment of group A and group B. The simulation results of gas pipeline displacement are shown in figure 2 and figure 3.
Figure 3. Pipeline displacement diagram of group B.

According to the simulation results of pipeline displacement in two groups of soil, the maximum pipeline displacement in group A is 0.75mm, and that in group B is 0.51mm, and the pipeline displacement decreases gradually from near to far where the load is applied. Since the wheel excavator with a weight of 13.5t is referred to in this paper, this excavator belongs to the type of wheel excavator with a relatively large body size, but the gas pipeline deformation caused by rolling is small. Therefore, it can be inferred that the rolling of most wheel excavators causes less damage to the pipeline.

At the same time, comparing the soil simulation results of group A and group B, it can be found that the soil environment has a great influence on the rolling effect of vehicles. In the condition of sandy clay in group B, the pipeline displacement caused by excavators was decreased to a certain extent compared with that in the condition of hard clay in group A.

4. Heavy trucks crush pipes
The crushing of pipes by heavy trucks is the most common situation encountered in daily operations. During the construction process, there are often heavy trucks to and from the pipeline, and they often cross the pipeline during the transportation [7]. Although the large trucks are equipped with multiple tires to disperse the load, some trucks with large load will still lead to the deformation of the pipeline, which will affect the safe operation of the pipeline.

4.1. The application of heavy truck loads
In practice, heavy trucks pass over buried pipelines in a variety of directions, so dynamic loads are applied to the soil in this paper, which can be divided into vertical pipeline directions and parallel pipeline directions for simulation [8].

In order to facilitate the finite element analysis, the effective contact surface between heavy truck tires and the ground is regarded as a rectangle. In this paper, the moving load is applied by referring to a 10-wheel 60t truck. It is assumed that the weight of the whole vehicle is evenly distributed among 10 wheels. The loading rectangular area is 0.36m×0.24m, and the ground pressure can be calculated as 0.7MPa.

Suppose the vehicle passes through the pipeline at the speed of 20km/h, and the dynamic load is applied by setting a certain number of load steps to form a load belt.

4.2. Analysis of calculation results
In the environment of medium hardness clay, the finite element model was calculated. When the truck rolled the pipeline along the parallel direction of the pipeline, in view of the symmetry of the pipeline and the repeatability of the pipeline model, in order to reduce the calculation and avoid unnecessary repetition, only 6m long pipe segment was taken as the simulation result, as shown in figure 4.
Figure 4. Parallel pipeline direction.

The displacement diagram shows the result after the truck passes by, so most areas have some deformation. As can be seen from the results in the figure, when the heavy truck passes over the buried pipeline in the direction of parallel pipeline, the maximum displacement of the pipeline is 1.3mm, indicating that the truck load has a significant impact on the pipeline and a large range. This is because during the driving process, the truck continuously rolls over the pipeline, and the simulated pipeline is in the deformation process for most of the time, resulting in obvious displacement of the pipeline and certain damage within the scope of action.

When the truck rolls down the pipeline in the vertical direction of the pipeline, the simulation results are shown in figure 5.

Figure 5. Vertical line direction.

As shown in the figure, the maximum displacement of the pipeline is 0.89mm when the heavy truck passes over the buried pipeline in the direction of the vertical pipeline. Compared with the results of rolling in parallel pipeline, rolling in vertical pipeline has a smaller displacement and a smaller range. This is because the load on the pipeline is affected for less time when the truck passes in the vertical direction of the pipeline, resulting in less displacement of the pipeline.

5. Preventive measures for rolling pipes by construction vehicles

5.1. Popularize construction vehicle monitoring technology
With the rapid development of economy, construction phenomenon exists everywhere. However, due to the limited working capacity of the line group staff and the large scope of the pipeline, it is difficult to achieve real-time monitoring of the construction behavior around the pipeline. Therefore, we need to develop and popularize monitoring technology, such as setting up cameras with identification function along the line, or infrared warning system, etc [9]. All these can effectively improve the monitoring efficiency of construction vehicles and ensure the safe operation of pipelines.

5.2. Strengthen the intensity of inspection
Through the inspection work, can discover in time causes the gas transmission pipeline damage construction behavior, can effectively avoid the construction vehicle to the gas transmission pipeline
rolling. Therefore, it is necessary to increase the intensity of the patrol, increase the patrol personnel investment [10]. At the same time should also pay attention to the construction of the report, can let the line group personnel focus to carry out the patrol work.

5.3. Improve public quality

Improving public quality plays an important role in reducing third-party damage to pipelines. By issuing public announcements, conducting public education and media publicity, and even through appropriate incentive mechanisms, relevant agencies can strengthen regular conversations or assessments with residents near the pipeline, so as to improve public awareness of the safe operation of the pipeline and make the public take the initiative to become the protector of the pipeline.

6. Conclusion

Through the finite element analysis of the construction vehicle rolling gas pipeline, it is concluded that the factors that affect the deformation degree of the gas pipeline are not only the vehicle weight and the buried depth of the pipeline, but also the soil environment and the driving mode of the vehicle. For pipelines buried 1.2m deep and covered with even and dense soil layer above the pipelines, the pipeline displacement caused by construction vehicles is not obvious, but the quality of vehicles passing above the pipelines still needs to be strictly controlled, because construction vehicles rolling buried pipelines for a long time will lead to the fatigue failure of the pipelines. Therefore, we should strengthen the integrity management, to ensure the safe operation of the pipeline.

References

[1] Seung-Mok Shin, Jin-Ho Suh, Jae-Sung Im, et al. Development of Third-Party Damage Monitoring System for Natural Gas Pipeline, J. Journal of Mechanical Science and Technology. 2003. 17(10): 1423-1430.

[2] Moghaddas Tafreshi, S.N. , O. Khalaj. Laboratory tests of small-diameter HDPE pipes buried in reinforced sand under repeated-load, J. Geotext Geomembr, 2008, 26(2): 145-163.

[3] Yimsiri S, Soga K, Yoshizaki K, et al. Lateral and upward Soil-Pipeline interactions in sand for deep embedment conditions, J. Journal of Geotechnical & Geoenvironmental Engineering, 2004. 130(8): 830-842.

[4] Peishi Yu, Jinjie Lv, Junhua Zhao. Finite Element Simulations of Dynamic Fracture of Full-Scale Gas Transmission Pipelines, J. Acta Mechanica Solida Sinica,2018,31(03):357-368.

[5] Pavanaditya Badida, Yakesh Balasubramaniam, Jayapriya Jayaprakash. Risk evaluation of oil and natural gas pipelines due to natural hazards using fuzzy fault tree analysis, J. Journal of Natural Gas Science and Engineering. 2019. 66(000): 284-292.

[6] T. Bajcar, F. Cimerman, Sirok B, et al. Impact assessment of traffic-induced vibration on natural gas transmission pipeline, J. Journal of Loss Prevention in the Process Industries, 2012, 25(6): 1055-1068.

[7] Ta Duy Hien, Nguyen Duy Hung, Nguyen Trung Kien, et al. The variability of dynamic responses of beams resting on elastic foundation subjected to vehicle with random system parameters, J. Applied Mathematical Modelling, 2019, 67: 676-687.

[8] Neacsa Adrian, Dinita Alin, Pawel Baranowski, et al. Experimental and numerical testing of gas pipeline subjected to excavator elements interference, J. Journal of Pressure Vessel Technology, 2016, 138 (3): 1-9.

[9] Daniel C. Brooker. Experimental puncture loads for external interference of pipelines by excavator equipment, J. International Journal of Pressure Vessels Z Piping, 2005, 82(11): 825-832.

[10] Mingjiang Xie, Zhigang Tian. A review on pipeline integrity management utilizing in-line inspection data, J. Engineering Failure Analysis. 2018. 92(000): 222-239.