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Mechanical response of buried polyethylene pipelines under excavation load during pavement construction

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ABSTRACT

Polyethylene (PE) pipelines are the most popular kinds of urban gas pipelines used in industry. With rapid development of urban pavement construction and increasing demand of natural gas in China. Urban gas pipe accidents caused by pavement mechanical construction have taken place more frequently in recent years, which becomes one main reason for accidents caused by third party damage. Thus, it is of great importance to investigate the failure mechanism of urban pipeline under mechanical excavation for safe operation of urban gas pipelines. A rigorous 3D finite element model was established for mechanical response of PE pipe under mechanical excavation in this study. Soil, tooth of the mechanical excavator and pipe were all modelled by continuum solid elements. Surface to surface contact algorithm was utilized simulating the actual interaction between excavation tooth, pipe and soil. Failure procedure of PE pipeline under excavation load was investigated in detail in a baseline analysis based on two commonly adopted criteria, the stress based failure criterion and the strain based criterion. Parametric analysis was also conducted to discuss the effects of excavation position, pipe diameter, pipe wall thickness and internal pressure on PE pipe's mechanical response. Results show that, large stress and strain will occur at longitudinal ends of the dent in the pipe induced by excavation load. And large ovality will occur in the whole contact area of the pipe.

The strain based criteria is more suitable for safety assessment of PE pipe, as the outstanding plastic performance of PE material. The excavation position and internal pressure have little influence on pipe's response, while increasing the pipe diameter and wall thickness can decrease the pipe stress and ovality to a certain extent.

1. Introduction

Urban gas pipelines are the main choose for gas transmission in urban areas. Urban gas pipelines are mainly made of Polyethylene (PE) materials and low strength carbon steel. With the rapid development of urban construction and increase demand of urban natural gas in China, the number of third party induced urban gas pipeline accidents increases [13]. Li et al. [14] summarized the accident data in recent five years for urban gas pipelines operated by KunLun Energy Company, the largest urban gas company in China, as shown in Table 1. He concluded that the third party damage has become the main pipe failure reason for urban PE pipes. There are two main reasons for this phenomenon: 1. The pipe strength of urban gas pipes is much smaller than line-pipe steel made long distance pipelines, which makes them more vulnerable. Especially for PE pipes, they can be easily crashed under concentrated

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Table 1
Statistical data for urban gas pipeline accidents [13].

Accident reasons	Accident numbers	Percentage%
Third party damage	248	37.74
Construction weakness	114	17.35
Material aging	34	5.18
Corrosion (steel pipes)	101	15.37
Material defects	68	10.35
Management	31	4.72
Others	61	9.29
Totally	657	100

mechanical excavation load. Sometimes, when the dipper-teeth of the excavator is sharp, the pipe surface might be punctured directly; 2. The construction activities in urban areas are frequent, especially for urban pavement constructions. Fig. 1 shows two urban PE gas pipeline accidents caused by pavement construction in City Harbin, China. It can be found that, these natural gas pipelines are always located in public areas, near residential buildings, markets or other facilities crowded with people, which makes these accidents more dangerous. Thus, conducting failure analysis of urban gas pipelines under mechanical excavation is of great significance for engineering practice.

A series of literatures are available for mechanical behaviour analysis of buried pipelines under third-party damages. And because the mechanical response of pipe structure under this loading condition is highly nonlinear and complicated. Experimental investigations and numerical simulations are commonly adopted methods. Valuable works have been conducted by Brooker [2,3] for analyzing the failure behaviour of buried X65 steel pipeline under direct excavation load of some typical dipper-teeth. He conducted both experimental and numerical investigation for relationships of the limit excavation load with pipe geometrical sizes. Yao et al. [35] studied the dynamic and static response of steel pipe under excavation load, and found that the dynamic effects on steel pipe under excavation load. Yang et al. [34] studied the influences of excavation angle of the excavator-tooth on X65 pipe's mechanical response without considering the effects of surrounding soils.

Some similar researches were also conducted for failure analysis of pipeline under other kinds of third-party damages. Liu et al. [20] proposed a limit pressure prediction model for steel pipeline with dents induced by impact loads. Zhang et al. [37,38] investigated the collapse behaviour of buried steel pipes under rock impact. Zhang L. et al. [38] studied the pipe's stress, plastic strain and deformation under explosion load using nonlinear finite element method. Guo Y.B. et al. [7] discussed the influences of gas pipe explosion accidents on adjacent pipes. Luo X.P. et al. [24] conducted numerical investigation for strength failure of buried PE

a) Accident case 1

b) Accident case 2

Fig. 1. Urban PE gas pipes accidents caused by mechanical exactor during pavement construction.