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Modelling of defective pipe behaviour and surrounding soil response

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Keywords: Buried defective pipeline, Nor-sand model, Soil-pipe interaction, Finite-element analysis

1 INTRODUCTION

Buried pipelines are widely used for urban water and gas network. Subject to ageing pipe material and changing surrounding ground conditions, many miles of pipes are inevitably deteriorating with considerable defects in the long term. Due to damaged pipes, many cases[1] of ground subsidence and sinkholes (Fig.1) in metropolitan areas have been reported worldwide. Some studies[2, 3] have shown that ground subsidence is often caused by the formation of internal voids and soil erosion induced by the defects of pipeline.



Fig. 1. Cases of ground subsidence due to defective pipes

In the past, there have been many studies[4, 5] about the formation of the voids in the embankment dam, but only few focus on the defective pipeline and induced surface subsidence. More recently, based on a small-scale lab test[6], a 2D soil-fluid coupled FE analysis was used to develop a comprehensive understanding of the internal voids and erosion mechanism due to defective pipes, in which a governing equation of erosion rate considering fines content was proposed. Although the simulation results show an agreement with lab tests results, the mechanical behaviour of the defective pipe was ignored in the model. In addition, Mohr-Coulomb model was used to describe the sandy soil behaviour in the research, which can poorly describe the dilatancy and softening behaviour of sandy soil.

In this study, in order to investigate the behaviour of buried defective pipe and surrounding soil more accurately, firstly a 3D model was built using ABAQUS finite element software package, where the pipe and characteristics of soil-pipe interaction are modelled. Secondly, an advanced state parameter-based model called Nor-sand model[7] was used to represent the stress-strain behaviour of sandy soil. Thirdly, the soil-fluid coupling incorporating with fine particles content coupled with Nor-sand model was used to study the influence of seepage force and hydraulic head on soil erosion and void formation.

2 METHODOLOGY

1. Based on the lab tests, a 3D model was developed where the soil was modelled by using C3D20P element type while the pipe was modelled with SR4 shell element, and the contact model was also adopted. The computed 3D results were compared with experimental tests results.
2. The soil constitutive model was using the Nor-sand model, which considered the dilatancy of soil by state parameter(ψ). The fine content of sand around the defect was used to describe the soil erosion and void formation. The governing equation analysis of fine content was coupled in Nor-sand model in ABAQUS.
3. A series of parametric studies were performed to evaluate the effect of different defect sizes, hydraulic head and etc.

3 RESULTS & DISCUSSIONS

1. Based on the comprehensive 3D analysis, the results showed that the strain and stress contours of pipe and formation characteristics of void obtained from simulation results match better with the experimental data than the computed 2D results.
2. It can be observed from the process of soil erosion, the seepage force developed due to the defect, and the pore pressure above the crack remained to zero from the beginning. The rate of the loss of fine particles from pipeline crack was slowly reduced until a void area with zero fine content was formed above the crack.
3. The factors of materials of soil and pipe, defect size and hydraulic head had great influence on the formation of voids around the defects, especially the factor of hydraulic head.
4. It can be seen from the deformation and stress of the pipeline, the formation of the void above the defect will further damaged the pipe due to the soil arching effect.

4 CONCLUSIONS

Investigating the 3D behaviour of buried defective pipeline influenced by surrounding soil movement can be effectively employed to minimize the pipe further damaged, optimize pipe design and provide promising reference to avoid ground subsidence.

In this paper, based on the experiments, a series of FE models were conducted and the simulation results were in good agreement with lab results. The performance of the pipeline and the characteristics of the surrounding soil can be well described in 3D simulation. Besides, this paper focused more on the advanced Nor-sand model to the interaction of soil and defective pipe and showed a different approach to describe soil behaviour. Moreover, the influence of the interaction law of the contact surface on the mechanical response of pipeline and the void formation plays an important role in the soil-pipe interaction and cannot be ignored.

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