A NUMERICAL STUDY ON THE SHAPE CHARACTERISTICS OF CIRCULAR UNDERGROUND CAVITY

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Abstract - In recent years, ground subsidence phenomenon frequently occurs in the world. The Korean government has enacted a special law on underground safety and the law will be enforced from January 1, 2018. Under this law, underground excavation should be assessed for underground safety impacts. After excavation construction, periodic geophysical surveys should be conducted to investigate the occurrence of underground cavities. When underground cavities were discovered, the underground safety was assessed through numerical analysis. However, there is controversy because the method of numerically modeling the discovered underground cavity has not been established. In this study, the effect of the depth of the underground cavity from the shape of the underground cavity to the underground cavity was studied using a continuum analysis program. In this study, a method to reflect the circular shape underground cavity to the numerical modeling is presented. The relationship between circular shape and depth of the underground cavity and the factor of safety calculated by the shear strength reduction method (SSR) is presented. The results of this study are expected to be basic data on underground safety impact assessment.

Index Terms - Underground Cavity, Numerical Analysis, Ground Subsidence, Shear Strength Reduction Method (SSR)

I. INTRODUCTION

Many research works are working on the influence factor, cause and mechanism of ground subsidence phenomenon like sinkhole, porthole. When a underground cavity is found with geophysical exploration methods like GPR(ground penetrating radar), electrical resistivity survey, the researches about the stability of it are not sufficient.

As the research of Lee et al. (2015), one of main factors occurring ground subsidence is the creation of cavity. The causes of it are divvied into natural cause and artificial cause. In urban area, the leakage in old supply and drainage pipelines makes underground cavity. The ground subsidence as underground cavity made by leakage are frequently surveyed. (Lee et al., 2015; Jeong et al., 2017). Lee (2014) surveyed the damage of pipeline that the proportion of the cause of road subsidence in Seoul is 85%. The effects of compaction density, bad backfill, ground relaxation as freezing-thawing ground freezing are greatly influenced than cracks and corrosion of old pipeline. Most of the depth supply and drainage pipeline is within 1m and the depth of urban underground facility is within 3m..

The best numerical method to simulate the creation and propagation of underground cavity as the leakage at old pipeline is distinct element method considering particle's movements. Because the quantification of the properties of material is not easy, the simulations of the ground subsidence with this method at engineering part have some difficulties. So many researchers used the continuum numerical methods of FEM(finite element method), FDM(finite difference method) for simulation of the stability of underground cavity. FOS(factor of safety) of the underground cavity using numerical analysis is suggested (You et al., 2001; Drumm et al., 2009; Kim and Yang, 2016).

This study is focused on FOS of the underground cavity as leakage on pipeline. The numerical analyses are performed on small underground cavity of which the depth is within 1m and the area is $1m^2$ as the result of Seoul metropolitan government (2014). FOS of the circular cavity is calculated using FLAC3D (Itasca, 2012).

II. GROUND SUBSIDENCE AND UNDERGROUND CAVITY

The ground settlement is the worst phenomena occurring in ground subsidence. The ground subsidence is divided as 4 types. First, ground settlement as construction of an underground structure is occurred as the result of loosening ground in excavation and construction a structure. Second, mining makes ground settlement. Third, melting ground as rainfall or groundwater is induced it. Fourth, down of groundwater level. The ground settlement is occurred as the result of lowering groundwater level at Songpa area in Seoul in 2014. Lowering groundwater level is surveyed as natural drawdown and artificial drawdown from excavation. The crack of pipeline, the one of settlement reasons is reported at deteriorated pipeline in urban area (Lee., 2014; Seoul metropolitan government, 2014).

Fig. 1 shows the sink-hole occurred at Florida and

Guatemala. A sink-hole is mainly reported abroad, karast area like KangwonDo Samcheok, Yonguel have high possibility of it than other area. Fig.2 shows that circular ground subsidence with diameter 16m occurred at Inchon subway construction site in 2012. Excavation tunnel in underground made the settlement on upper ground layer and leakage in water pipeline weight on the settlement. Huge soil erosion occurred and underground cavity was madden(Seoul metropolitan government, 2014).



(a)Florida sinkhole



(b) Guatemala sinkhole

Fig. 1. Naturally occurring sinkholes (Seoul metropolitan government, 2014)



Fig. 2. Road subsidence in Incheon, Korea (Seoul metropolitan government, 2014)

III. THE EVALUATION METHOD USING SHEAR STRENGTH REDECTUION

The research of the stability of underground cavern with safety factor for tunneling, construction of mine stope, cavern for underground storage were performed (Hoek and Brown., 1980; You et al., 2001; Kim., 2013; Kim., 2014). "The special law about underground safety management for the prevention of ground settlement" advices the calculation of safety factor using shear strength reduction method for the evaluation of underground safety. This study calculate factor of safety for the safety of underground cavity using shear strength reduction method with FLAC3D. This study suggest the evaluation method about the stability of cavity occurred around old supply and drainage pipeline and the stability of underground cavity based on factor of safety including shear strength reduction method.

You et al. (2001) suggested the evaluation method using shear strength reduction method to calculate safety factor of excavated tunnel. The strength parameters of ground, cohesion(c) and internal friction angle(φ) are used factor of safety with trial factor of safety using trial and error method. Initial strength parameters are decreased as linear decline ratio like equation (1) and (2). Fig..3 shows flow for calculation of safety factor. Fig.4 shows the relationship between shear strength and trial shear strength. When failure around tunnel occurs, trial factor of safety at the moment is the factor of safety of tunnel.

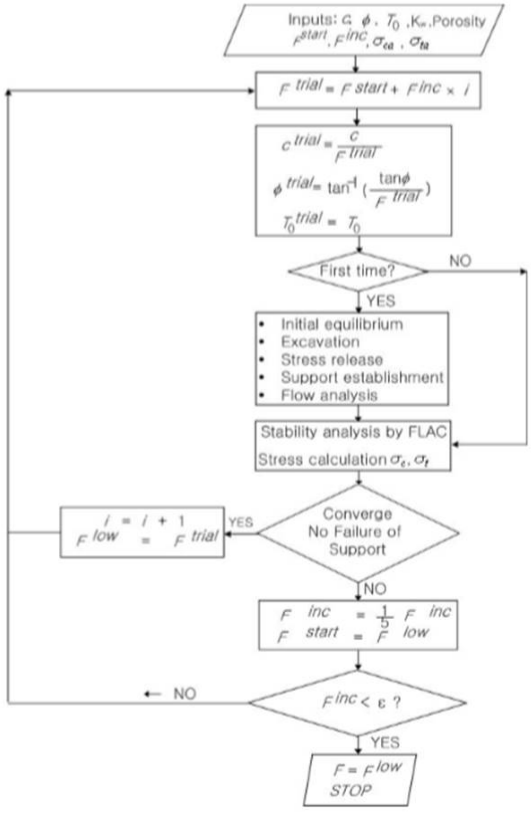


Fig. 3. Flowchart for calculation of FOS (You et al., 2001)

$$c^{trial} = \frac{c}{F^{trial}} \quad (1)$$

$$\varphi^{trial} = tan^{-1}\left(\frac{1}{F^{trial}}\tan\varphi\right) \quad (2)$$

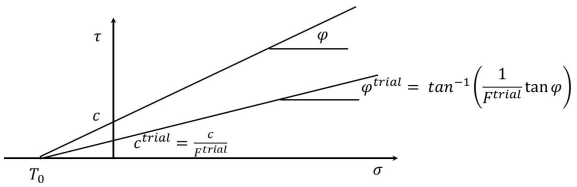
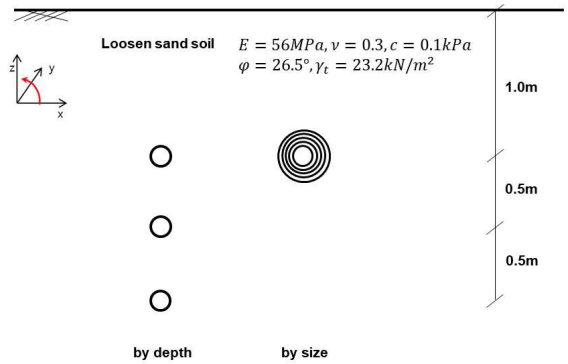


Fig. 4. Shear strength and trial shear strength relationship (You et al., 2001)

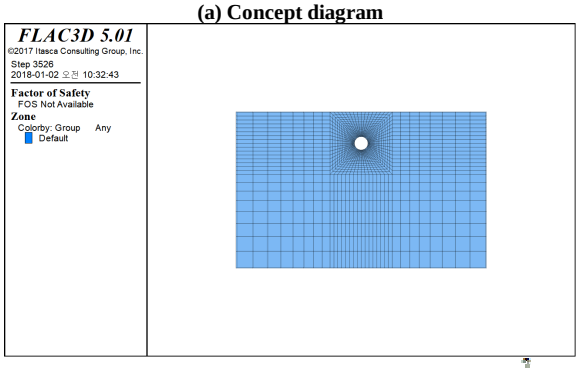
IV. NUMERICAL ANALYSIS CONSIDERING THE GEOMETRIC FACTOR

1) Analysis condition

To calculate the stability of underground cavity based on the factor of safety using shear strength reduction method, the geometric conditions of underground cavity are modeled using FISH which is the internal language in FLAC3D. Fig.5 shows soil condition and geometric conditions in FLAC3D. Soil strength parameter in backfill area above pipeline is used the result of Kim et al. (2017). Mohr-Coulomb model is used, deformation modulus (E) is 56MPa, poisson's ratio (ν) is 0.3, total density(γ_t) is 23.2kN/m^2, cohesion (c) is 0.1kPa and internal fiction angle (φ) is 26.5°. Because this study is the initial research of safety cavity using shear strength reduction method, this study doesn't consider the effect of ground water, surcharge load, non circular shape.



(a) Concept diagram



(b) FLAC3D feature (depth=1.0m, circular, area=1$^{m^2}$)

Fig. 5. Soil and representative underground cavity condition

Table 1. Input for the circular underground cavities

Area (m^2)	1	0.8	0.6	0.4	0.2
Diameter (m)	1.13	1.01	0.87	0.71	0.50

2) Numerical analysis results

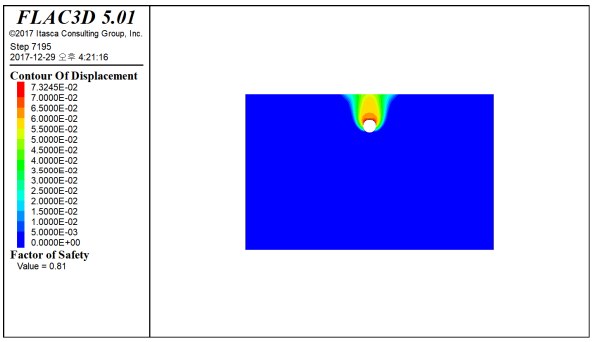


Fig. 6. Displacement contour at the conditions of diameter 0.83m, depth 2m

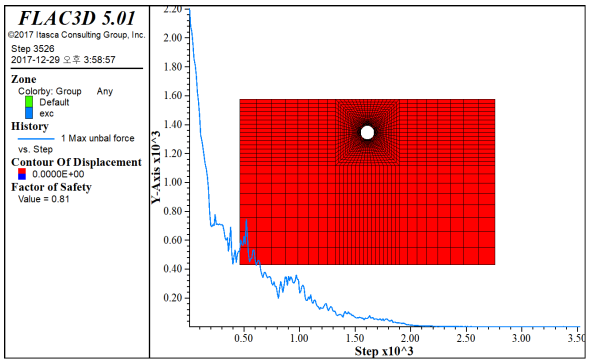


Fig.8. FOS(Factor of Safety) and convergence graph of unbalanced force at the conditions of diameter 0.83m, depth 2m

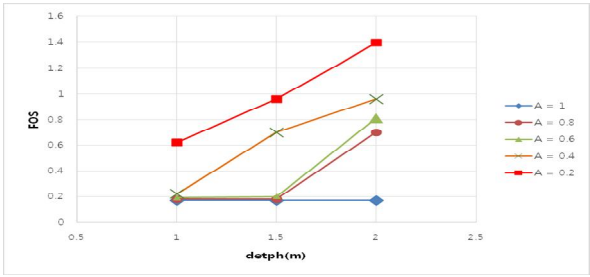


Fig.9. the varation of FOS as depth and area of cavity

As depth is increased, FOS(factor of safety) is increased. As area is increased, FOS is decreased. The result of area 1m^2 has little variation. When the ratio of area over depth is big, cavity is unstable.

Depth(m)	Area(m^2)	Diameter(m)	FOS
1.0	1.0	1.13	0.17
1.5	1.0	1.13	0.17
2.0	1.0	1.13	0.17
1.0	0.8	1.01	0.18
1.5	0.8	1.01	0.18

2.0	0.8	1.01	0.7
1.0	0.6	0.87	0.19
1.5	0.6	0.87	0.2
2.0	0.6	0.87	0.81
1.0	0.4	0.71	0.22
1.5	0.4	0.71	0.7
2.0	0.4	0.71	0.96
1.0	0.2	0.50	0.62
1.5	0.2	0.50	0.96
2.0	0.2	0.50	1.39

CONCLUSION

1) The depth and area is import factor to decide factor of safety.
2) As FOS is increased, the depth is bigger and area is smaller.

Then further analysis for non-circular shape is needed. In next study the analyses of the equivalent area of ellipse compared to circular shape are performed, FOS is calculated with circular shape although real cavity is irregular shape or ellipse. In further study, 3D effect of cavity should be analyzed. As the result of it, 2D analysis equivalent result with 3D volume make similar results.

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