A NUMERICAL STUDY ON THE 3-DIMENSIONAL CHARACTERISTICS OF URBAN SMALL CAVITIES

[1]BYUNG-CHAN KIM, [2]JIN-HAENG LEE

Chief Researcher., Construction IT Laboratory., BasisSoft, Inc., Researcher., Construction IT Laboratory., BasisSoft, Inc..
E-mail: [1]bryan@basis.co.kr, [2]jhlee@basis.co.kr

Abstract - The special law on underground safety in Korea was enacted from January 1, 2018. When conducting the underground safety impact assessment under this Act, it is essential to investigate the occurrence and safety of underground cavities. When underground cavities were discovered, the safety of underground area around cavity was investigated through numerical analysis. In this study, the effects of small underground cavities considering 3D shapes were studied using a continuum analysis program and compared with the 2D results presented in previous study. Through this study, the relationship between the 3D shape characteristics of the urban small underground cavity and the safety factor 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 - Small 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).

After Rujikiatkamjorn et el. (2008) compared the results of 2D and 3D numerical analysis about consolidation method using ABAQUS,
he suggested the 2D result on plain strain condition is similar with the 3D result for vertical drain numerical analysis. Hungr et al. (1989) and Arellano and Stark (2000) were studied various slope stability methods like Bishop simple method. They were compared the difference between 2D and 3D numerical analysis with same properties and conditions. 3D numerical analysis for slope stability is important on not plane strain condition. Dhawan et al. (2002) was studied the characteristics between 2D and 3D FEM analysis of tunneling using Drucker-Prager model on non-homogenous rock mass. The result of 3D analysis was more closed with the measurement values on soft rock and multiple caverns conditions. On this study, the 3D characteristics of small cavity is investigated as the comparison between 2D and 3D numerical analysis.

II. THE STABILITY ASSESSMENT OF UNDERGROUND CAVITY USING SSR

Many researchers were studied the stability of underground cavity like tunnel, mine stope, storage cavern based on factor of safety(Hoek and Brown., 1980; Park and You, 1998; Kim., 2013; Kim., 2014; An et al., 2018). The underground cavity on this study is focused small urban cavity below asphalt road which occurred as leakage of old pipes.

Park and You (1998) suggested shear strength reduction method for the stability of tunnel on soft rock mass. The factor of safety is calculated using trail-error method with cohesion and internal friction angle.

Fig. 1 shows the flow chart of shear strength reduction calculations on FLAC2D. Initial strength values are decreased linearly like Eq(1) and Eq(2). Fig 2 shows the relationship between shear strength and trial shear strength. When the failure occurs, trial factor of safety is calculated and then it is the factor of safety of tunnel.

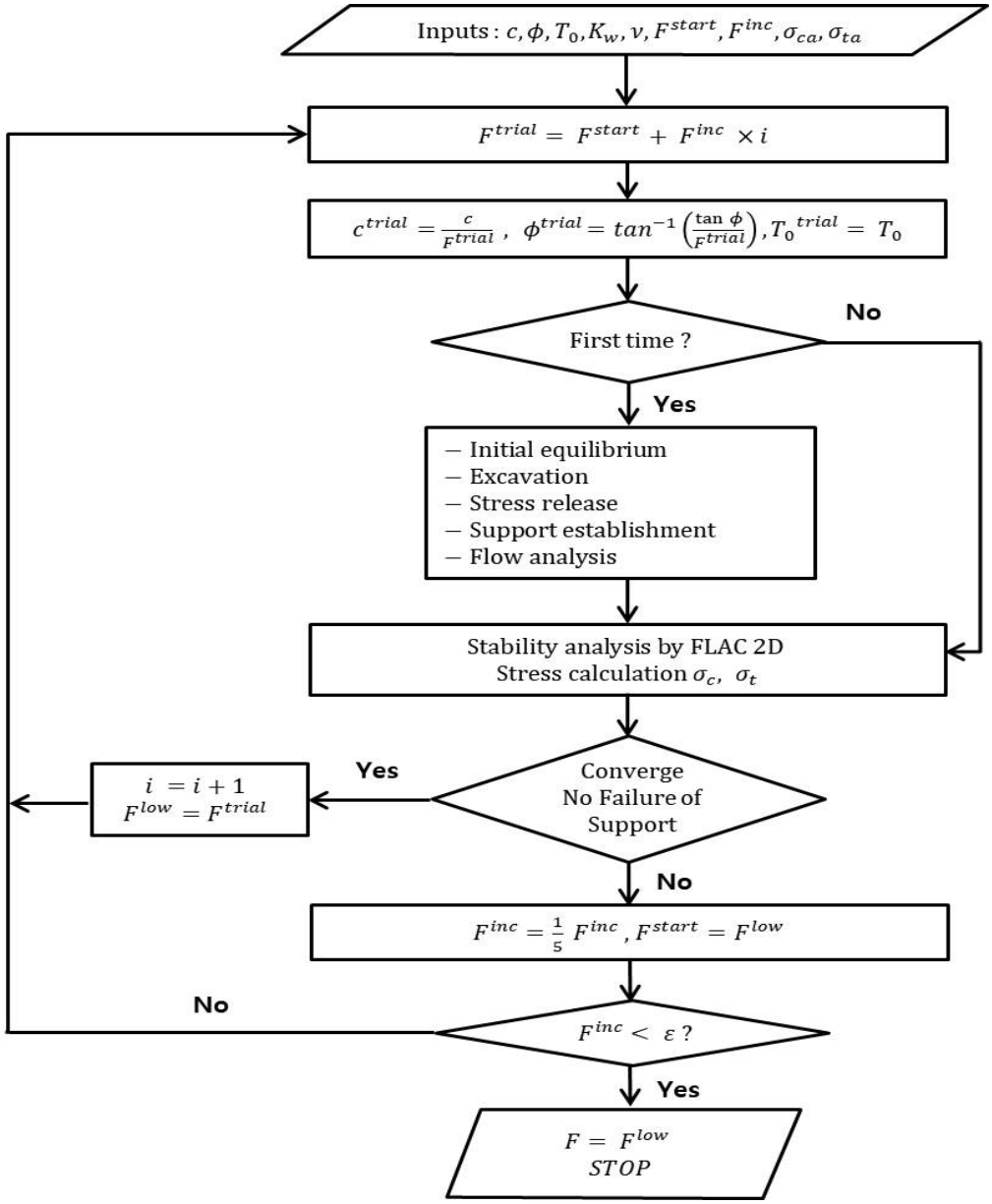


Fig. 1. Flowchart for the procedure of safety factor calculation (Park and You, 1998)

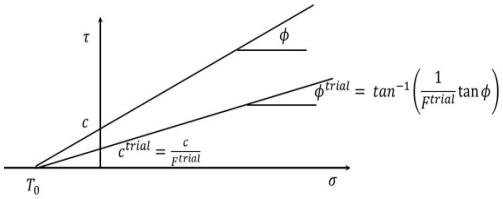


Fig. 2. Shear strength and trial shear strength relationship (Park and You, 1998)

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

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

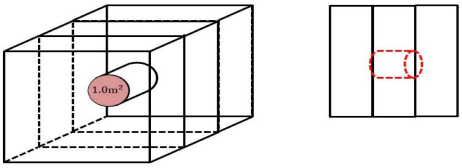
III. NUMERICAL ANALYSIS OF FOS CONSIDERING 3D SHAPE OF UNDERGROUND

1) The comparison of 3D Shape of cavity

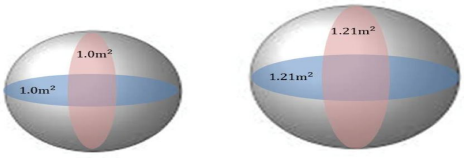
Shear strength reduction method described on chapter 2 is generally used on slope stability analysis. The stability of underground cavity like tunnel and cavern is examined with SSR. Park and You (1998) was studied SSR using 2D finite differential program FLAC2D. In general, Tunnel structure having homogeneous section and geological layers can be analyzed using plain strain condition,

2D analysis is substituted with 3D analysis. Small urban cavern occurred around old pipe should be considered 3D shape of it. On previous study (An et al., 2018) the assessment of stability of small urban cavity considering 2D shape characteristics was suggested. On this study

3D shape characteristics are considered and compared between the result 2D and 3D analysis. Fig. 3 and 4 shows the shape of underground cavity in 2D and 3D analysis. Fig. 5 shows the process of SSR calculation used on this study.



(a) Circular disk type (b) Side view of circular disk type



(c) Sphere type-1 (equal projected area) (d) Sphere type-2 (equal volume)

Fig. 3. Volume, area and diameter of 3D shape for underground cavities

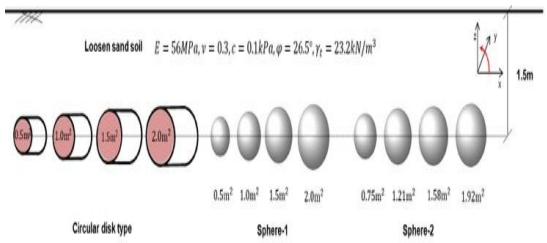


Fig. 4. Concept diagram of underground cavity condition for the choice of 3D shape

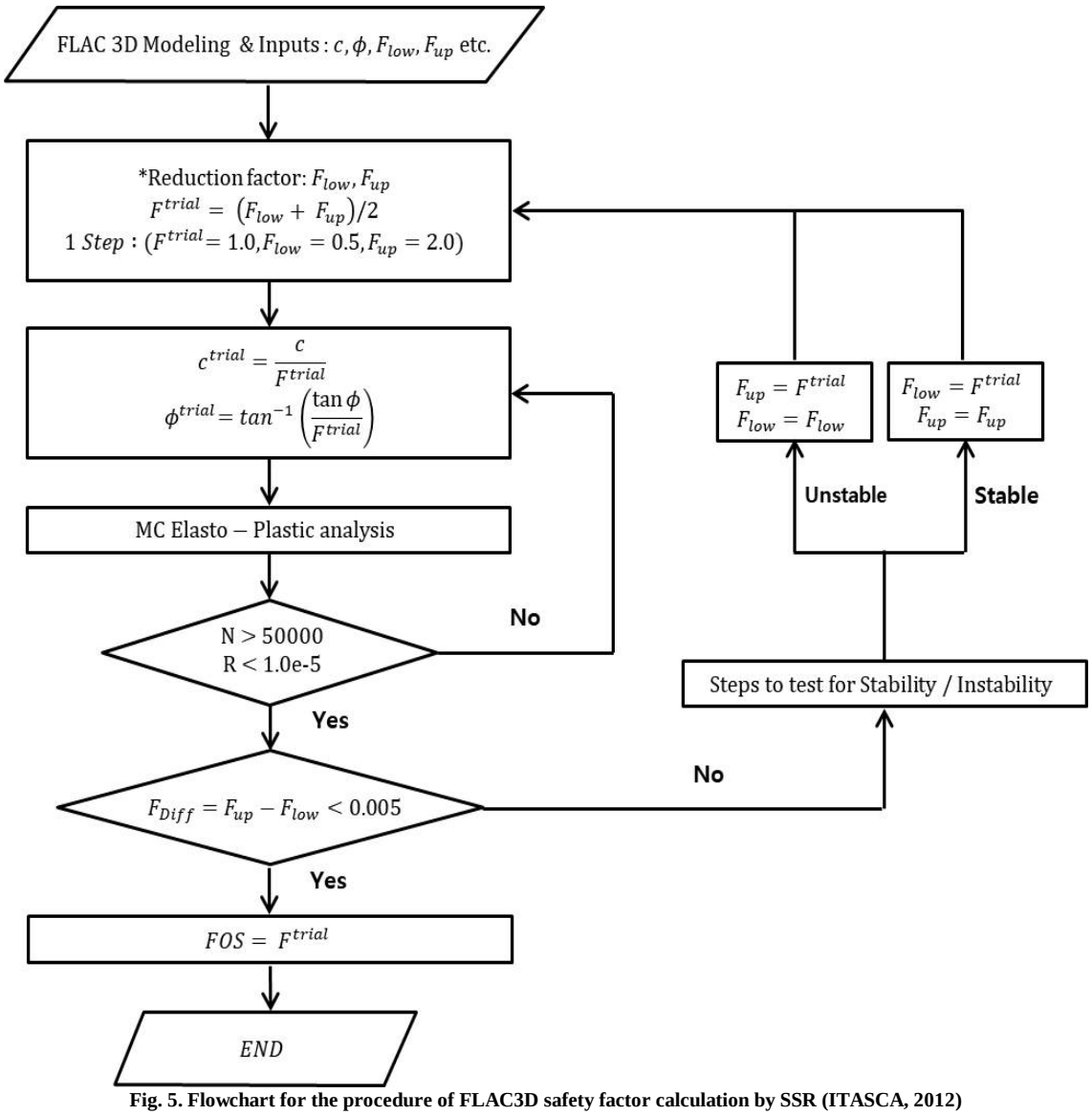
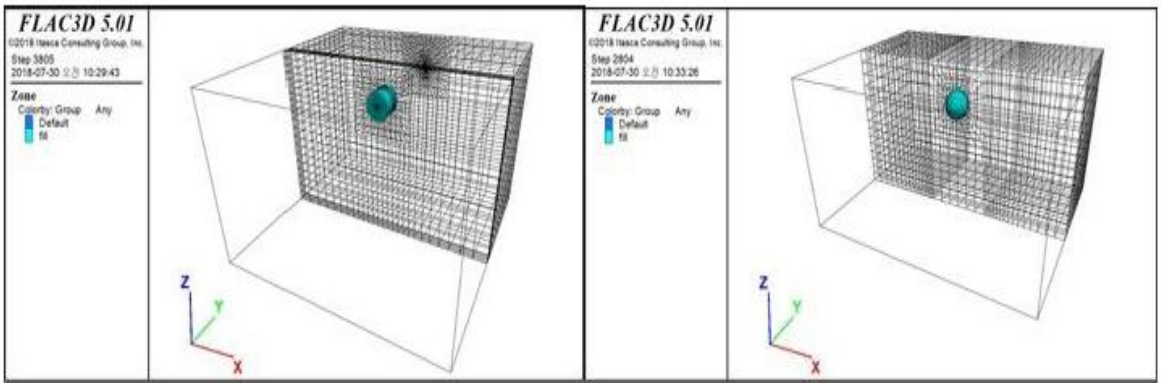


Fig. 5. Flowchart for the procedure of FLAC3D safety factor calculation by SSR (ITASCA, 2012)

Fig. 6 shows the 3D mesh modeling of FLAC3D on each condition.
Table 1 is summarized the relationship between projection area and FOS. As the result, sphere with same volume is used for the numerical analysis studies.

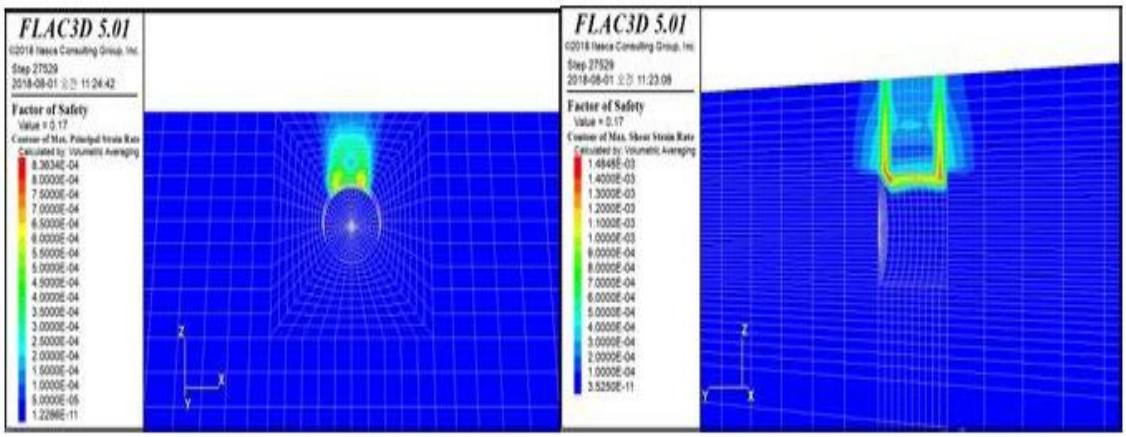


(a) Disk type (b) Sphere-2 type

Fig. 6. FLAC3D feature (depth=1.5m, projected area=1m^2)

Table 1. Factor of safety results of preliminary numerical analysis for the choice of 3D shape

	Projected area (m^2)	Factor of safety
Circular disk type	0.5	0.22
	1.0	0.17
	1.5	0.16
	2.0	0.15
Sphere-1 type	0.5	0.61
	1.0	0.28
	1.5	0.23
	2.0	0.20
Sphere-2 type	0.75	0.41
	1.21	0.25
	1.58	0.22
	1.92	0.20



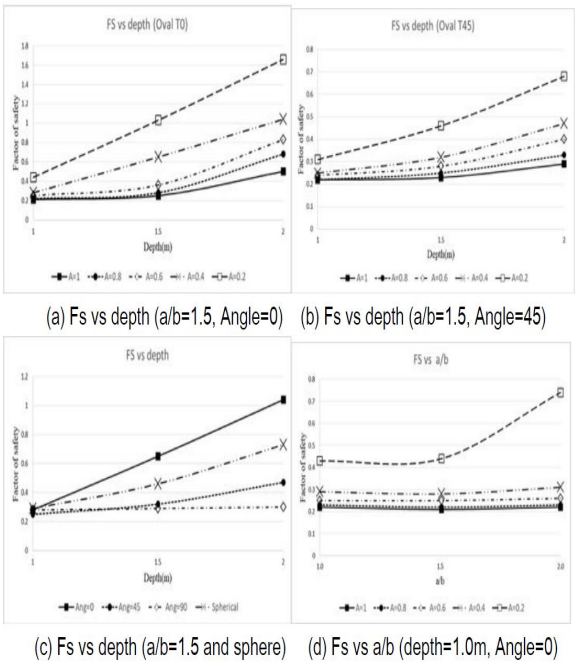
(a) Disk type (Fs=0.17) (b) Disk type (Fs=0.17)

Fig. 7. Factor of safety results and features of failure mode (depth=1.5m, projected area=1m^2)

1) The failure of 3D elliptical and spherical cavity

Table 2. Factor of safety results

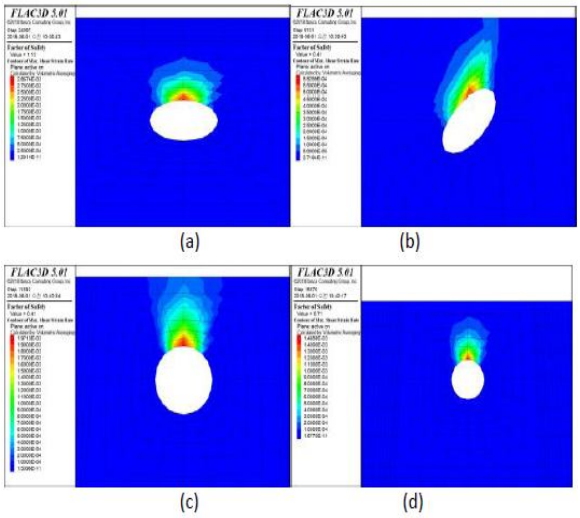
Angle (°)		Area (m²)	a (m)	b (m)	a/b	Factor of safety		
						Depth=1.0m	Depth=1.5m	Depth=2.0m
sphere		1.0	1.24	1.24	1.0	0.22	0.25	0.41
oval	0		1.51	1.00	1.5	0.21	0.25	0.50
	45					0.22	0.23	0.29
	90					0.26	0.25	0.27
sphere		0.8	1.15	1.15	1.0	0.23	0.27	0.53
oval	0		1.41	0.93	1.5	0.22	0.28	0.68
	45					0.22	0.25	0.33
	90					0.26	0.27	0.29
sphere		0.6	1.05	1.05	1.0	0.25	0.38	0.62
oval	0		1.28	0.85	1.5	0.25	0.36	0.83
	45					0.24	0.28	0.40
	90					0.26	0.31	0.36
sphere		0.4	0.91	0.91	1.0	0.29	0.46	0.73
oval	0		1.12	0.74	1.5	0.28	0.65	1.04
	45					0.25	0.32	0.47
	90					0.28	0.38	0.40
sphere		0.2	0.73	0.73	1.0	0.43	0.71	0.95



(a) Fs vs depth (a/b=1.5, Angle=0) (b) Fs vs depth (a/b=1.5, Angle=45)

(c) Fs vs depth (a/b=1.5 and sphere) (d) Fs vs a/b (depth=1.0m, Angle=0)

Fig. 8. Relationship of factor of safety with underground cavities shape, depth, area and a/b



(a) depth=2.0m, a/b=2.0, area=0.6, Angle=0, Fs: 1.13

(b) depth=2.0m, a/b=2.0, area=0.6, Angle=45, Fs: 0.41

(c) depth=2.0m, a/b=1.0, area=1.0, Fs: 0.41

(d) depth=1.5m, a/b=1.0, area=0.2, Fs: 0.71

Fig. 6. The results of factor of safety and maximum shear strain

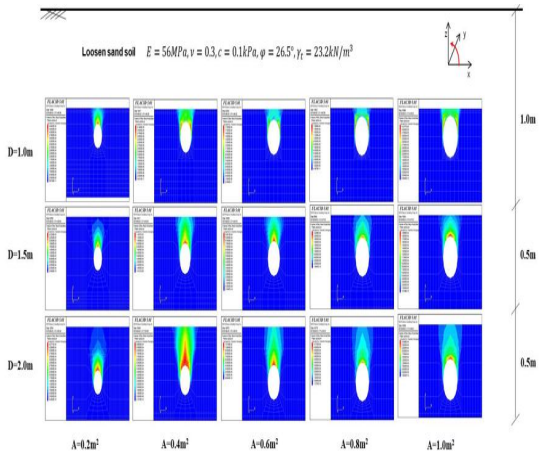


Fig. 6. Maximum shear strain rate for oval shape cavities (a/b=1.5, Angle=90)

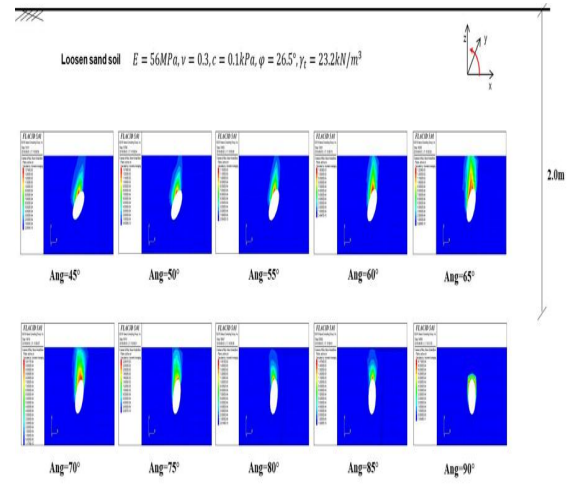


Fig. 7. Maximum shear strain rate of oval shape cavities according to rotation angle (Projected area=0.6, a/b=2.0, depth=2.0m, Angle=45~90\)

CONCLUSION

1) The factor of safety of spherical shape cavity is increased as increasing depth regardless size of it. When cavity under asphalt road is discovered, if the shape of it is close to spherical shape, SSR is good method for evaluate the stability of it.

2) The FOS of Ellpictical cavity is sensitive to depth and rotation angle. When the cavity is close to surface and the size of it is not small, engineer carefully apply SSR to evaluate FOS of it.
Then further analysis for various ground condition is needed. In next study the analyses, the effects of groundwater, asphalt pavement and vehicle load are performed, FOS is calculated

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