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Assessing the Effect of Underground Tunnel Diameter on Structure-Foundation-Soil Performance under the Kobe Earthquake

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Abstract**—**Today, developed and industrial cities have all kinds of sewage and water transfer canals, subway tunnels, infrastructure facilities, etc., which have caused underground cavities to be created under the buildings. The presence of these cavities causes behavioral changes in the structural behavior that must be fully evaluated. In the present study, using Abaqus finite element software, the effect of cavities with 0.5 and 1.5 meters in diameter at a depth of 2.5 meters from the earth's surface (with a circular cross-section) on the performance of the foundation and the ground (soil) has been evaluated. For this purpose, the Kobe earthquake was applied to the models for 10 seconds. Also, pore water pressure and weight were considered on the models to get complete results. The results showed that by creating and increasing the diameter of circular cavities in the soil, three indicators; 1) von Mises stress, 2) displacement and 3) plastic strain have had oscillating, ascending and ascending processes, respectively, which shows the relationship between increasing the diameter index of underground cavities and structural indicators of structure-foundation-soil.

Keywords**—**Underground excavations, foundation, structural substrates, Abaqus software, Kobe earthquake, time history analysis.

I. INTRODUCTION

IN urban areas, the existence of underground structures such as subway tunnels, sewers, etc. causes the behavior of structures located on the ground to change. When a subway tunnel is stimulated by dynamic loads, vibrations enter the underground tunnel and propagate in the ground in a wave motion. When the wave reaches the upper layers of the earth, the foundation of the building will shake. Also, reciprocally, the movements of the building cause vibrations in the tunnel structure. If there are terrible earthquakes or a small distance between the building and the tunnel, it is possible to cause high-level damage. Damage to underground structures such as the Japan Metro Tunnel (Fukuoka City - Southwest Japan) or land subsidence due to the failure of part of the underground tunnel in the hyogo-ken nambu (17 January 1995) earthquake has increased the importance of the role of underground tunnels in structural engineering and geotechnics [1]-[3].

Tsinidis et al. evaluated the seismic performance of tunnels with circular and rectangular sections. The results showed that the possibility of failure and failure in the tunnel with a rectangular section is higher [3]. Liu et al. evaluated the effect of twin tunnels on the performance of structures on the ground. The results showed that the highest amount of subsidence was created in sandy soils and in the upper surface of the tunnel [4]. Chen et al. evaluated the effect of circular tunnel profile on land subsidence. The results showed that as the amount of depression in the ground above the tunnel increases, the amount of subsidence increases [5]. Chen evaluated the effect of twin tunnels in the depth of the earth on the amount of soil subsidence, the results showed that the amount of subsidence decreased with increasing loading time on the ground surface [6]. Liu et al. evaluated the dynamic stability of underground tunnels on a formable bed. The results showed that increasing the diameter of the cavity did not directly increase the amount of soil subsidence [7].

(a)

(b)

Fig. 1 Damage caused by the Hyogoken-Nambu earthquake in 1995 on the ground and underground tunnel located deep in the soil [3]

II. METHODOLOGY

A. Software

The present study was performed using Abaqus cae / 6.12.3 software.

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B. Modeling Geometry

Modeling was performed using a combination of foundation and ground (soil) elements. The dimensions of the foundation and the ground (soil) are 10 × 10 meter and 0.4 × 2 meter, respectively, which will be placed on top of each other (Fig. 1). The base of the building is a strip foundation. Due to the large ratio of length to width in the foundation, it can be modeled in the flat strain mode. The soil above the base of the foundation is applied in a uniform tension on its sides. Also, due to the lack of extension of the rupture network in the upper part of the foundation, the shear strength of the soil in this area has been neglected.

C. Model Titles (Conditions for Digging Holes in the Soil)

The naming of the models created in the present study and how the cavity is located in the depth of the earth (soil) is presented in Fig. 1 and Table I.

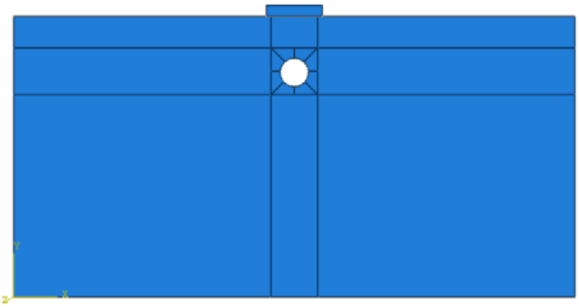


Fig. 2 Laying the foundation on the ground and making a hole in the ground (soil)

TABLE I
NAMING THE MODELS MADE IN ABAQUS SOFTWARE

H (meter)	R (meter)	Cavity	model name	Row
-	-	×	FS1	1
1.5	0.5	✓	FS2	2
1.5	1.5	✓	FS3	3

D. Material Specifications

In modeling, two materials, steel and soil, were used, the specifications of which are presented in Table II. In modeling sandy soils with a density of 40%, the internal friction angle and adhesion are 35 C and zero kilopascal, respectively. When using the Drucker–Prager (extended) model, the factors β and d should be calculated based on (1) and (2):

$$\tan\beta = \frac{3\sqrt{3}\ \tan\varphi}{\sqrt{9+12(\tan\varphi)^2}} \qquad (1)$$

$$\mathrm{d} = \frac{3\sqrt{3}c}{\sqrt{9+12\tan\varphi^2}} \qquad (2)$$

The parameters are as follows: β: Internal friction angle of the soil, d: Soil adhesion, φ: The internal friction angle of the soil.

The Drucker–Prager model was used in soil modeling, the specifications of which will be presented in Table III.

E. Load Elements

The weight loading is based on the mass equivalent of soil (ground) and the cavity water pressure loading is also applied to the model from the top surface of the soil. Seismic loading was performed using Kobe earthquake acceleration applications for 10 seconds (Fig. 3) and dynamic analysis of time history.

TABLE II
SPECIFICATIONS OF MATERIALS USED IN MODELING FOUNDATION AND BED SOIL IN ABAQUS SOFTWARE

Article title	Poisson's ratio	Modulus of elasticity	Density
Foundation	0.21	3000000000	2410
Soil	0.251	30000000	1550

TABLE III
MODEL SOIL SPECIFICATIONS IN DAGGER-PRAGER MODEL

Abs Plastic Strain	Yield Stress	Dilation Angle	Flow Stress Ratio	Angle of Friction
0	0.001	0.1	1	43.9

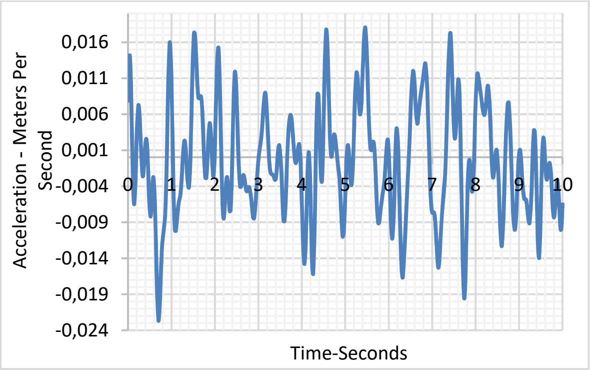
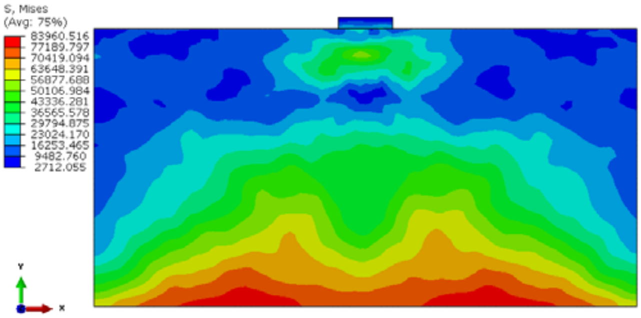


Fig. 3 Kobe earthquake acceleration-time curve

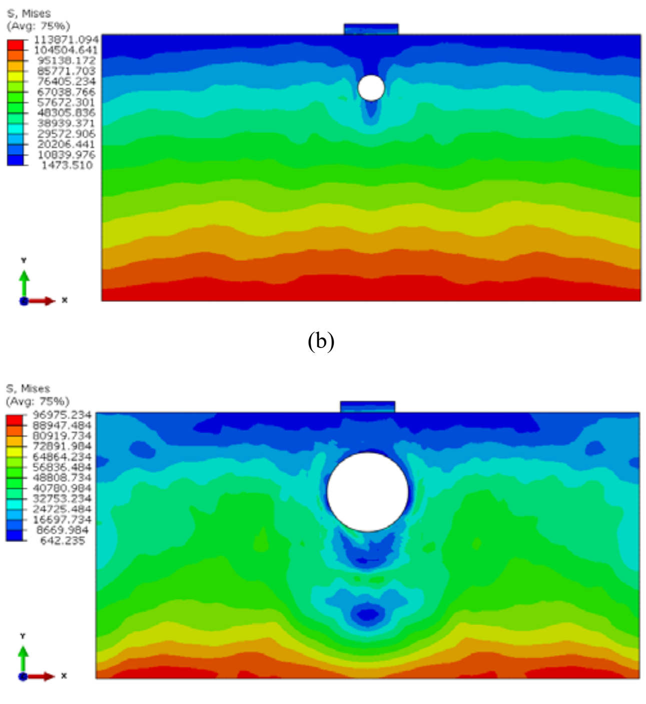
III. PRESENTING AND ANALYZING THE RESULTS

A. Von Mises Stresses

The results in Figs. 4 and 5 showed that the stress of von Mises had a variable trend with the creation and increase of the hole diameter and did not necessarily increase. The highest and lowest stress levels of the Monsoon Phone in the FS2 and FS1 models were generated at 83960 and 113871 megapascals, respectively.



(a)



(b)

(c)

Fig. 4 Von Mises stress in models; (a) FS3, (b) FS2 and (c) FS3 under dynamic analysis of time history with Kobe earthquake

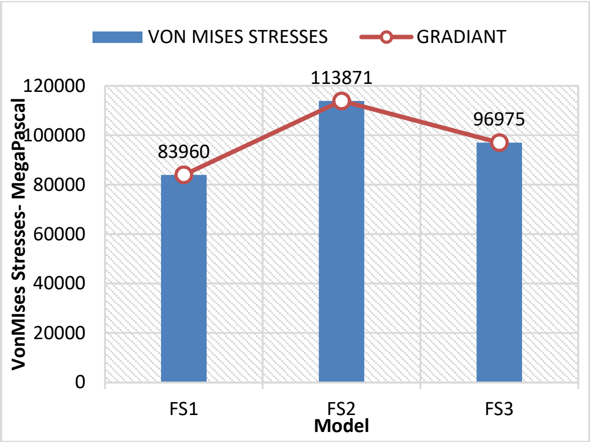


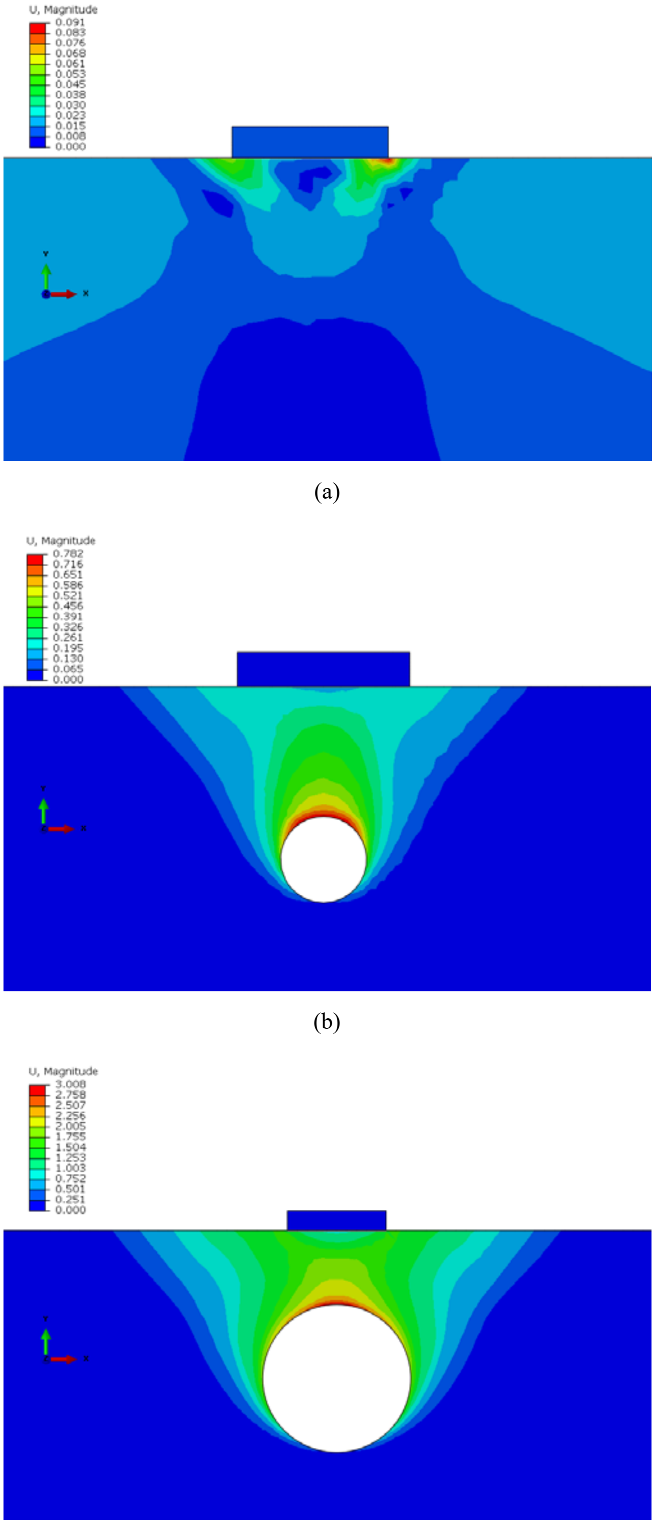
Fig. 5 Curve of the maximum amount of stress of the von Mises stress in the models; (a) FS3, (b) FS2 and (c) FS3 under dynamic analysis of time history with Kobe earthquake

B. Displacement

The results in Figs. 6 and 7 showed that the displacement had an upward trend with the creation and increase of the hole diameter. The highest and lowest values of displacement in FS1 and FS3 models were 0.91 and 0.008 meter, respectively.

C. Plastic Strain

The results in Figs. 8 and 9 showed that the plastic strain had an upward trend with the creation and increase of the hole diameter. The highest and lowest plastic strain values in FS1 and FS3 models were 0.91 and 0.008 m, respectively.



(a)

(b)

(c)

Fig. 6 Modification of models; (a) FS3, (b) FS2 and (c) FS3 under dynamic analysis of time history with Kobe earthquake

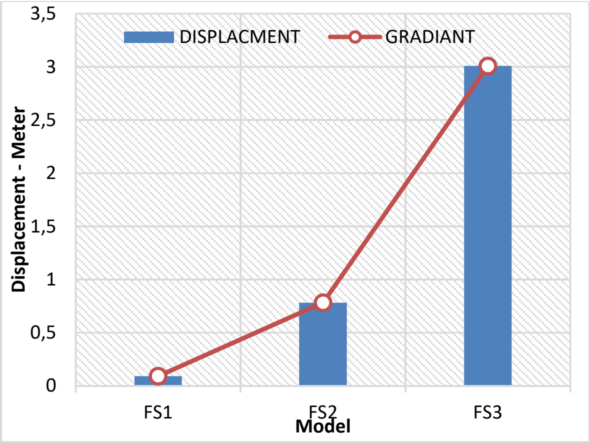
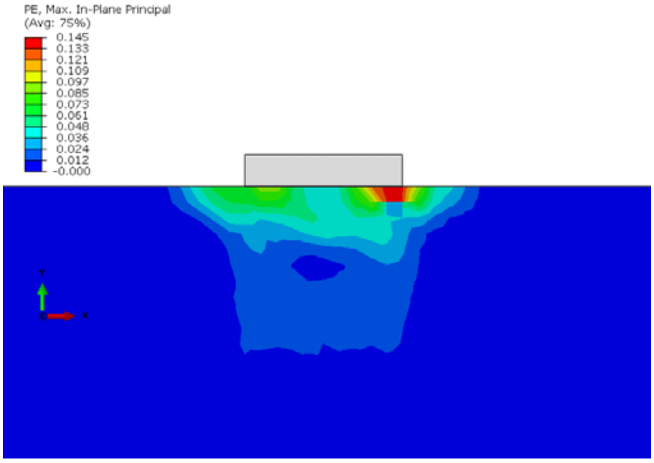
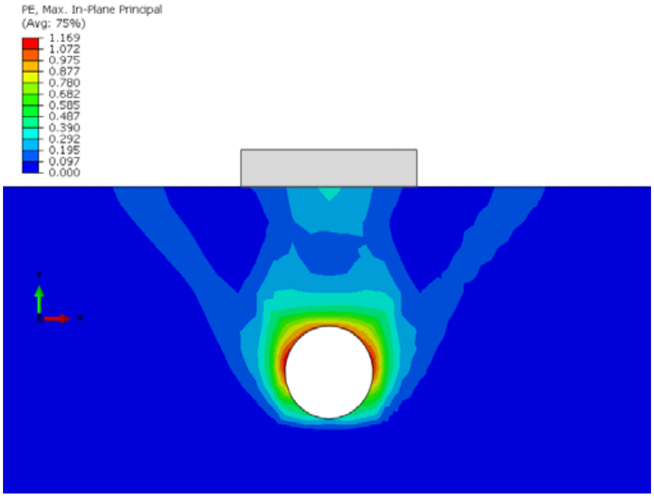


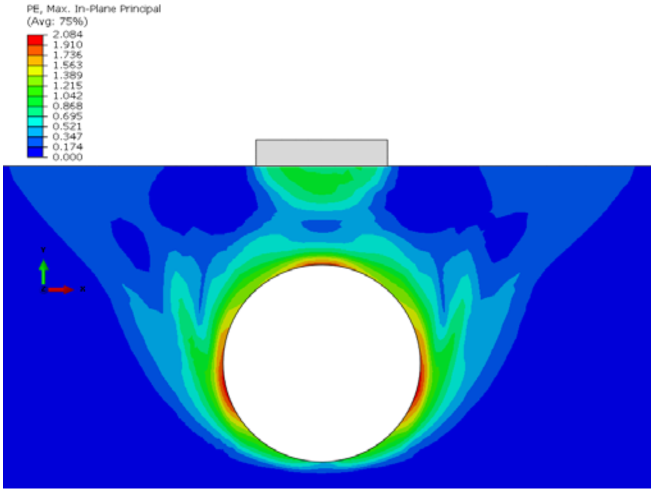
Fig. 7 Curve of the maximum amount of displacement in the models; (a) FS3, (b) FS2 and (c) FS3 under dynamic analysis of time history with Kobe earthquake



(a)



(b)



(c)

Fig. 8 Plastic strain models; (a) FS3, (b) FS2 and (c) FS3 under dynamic analysis of time history with Kobe earthquake

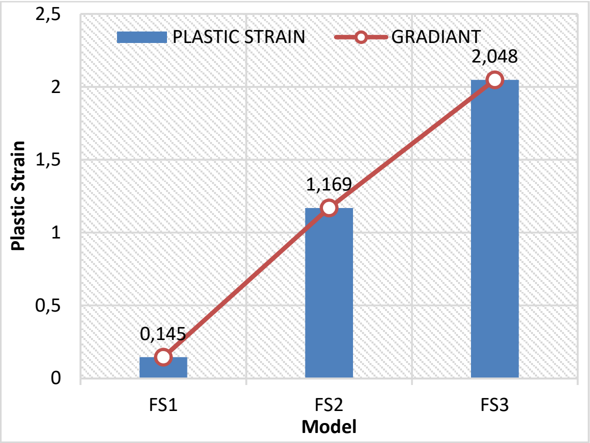


Fig. 9 Curve of the maximum amount of plastic strain in models. (a) FS3, (b) FS2 and (c) FS3 under the Kobe earthquake

IV. CONCLUSION

Direct connection between the two indicators: 1) There was no increase in the diameter of the cavity and 2) there was no stress on the table.

Direct connection between the two indicators: 1) There was an increase in the diameter of the cavity and 2) there was a change in location.

Direct connection between the two indicators: 1) There was an increase in the diameter of the hole and 2) there was a plastic strain.

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