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تأثير سماكة طبقة الرمل ومحتوى الرطوبة على سلوك المنشآت تحت الأرض تحت تأثير إنفجار سطحي

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الخلاصة

الانفجارات السطحية والجوفية تسبب بأضرار واسعة النطاق وتدمير لهياكل المباني. ويمكن لهذه الانفجارات بأن تولد صدمات أرضية كبيرة. وهناك عدة طرق للحد من هذه الآثار المدمرة. وإحدى هذه الطرق هي طريقة طبقة الرمال، وهذه الطريقة هي الطريقة الأكثر اقتصادية لأن طبقة الرمال تقلل موجات التوتر العالية وضرر هياكل المباني. وفي هذا البحث، تم التحقق من سلوك الأنفاق (هياكل تحت الأرض) مع طبقة الرمال ذات سماكات مختلفة ورطوبة مختلفة تحت تأثير انفجار سطحي بواسطة طريقة العناصر المحدودة. وتشير النتائج العددية على أنه مع زيادة طبقة الرمال والرطوبة، فإن تأثير الانفجارات على سطح الإنشاءات المشيدة تحت الأرض قد انخفض بشكل كبير.

The effect of sand layer thickness and moisture content on underground structures behavior due to surface blasting

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ABSTRACT

Surface and underground explosions make extensive destruction and damage to structures. These explosions can generate heavy shocks to ground. There are several approaches to reduce these effects. One way to reduce these damages is by sand layer, which is the most economically viable method. As the sand layer reduces high-frequency stress waves effectively, it decreases damage to structure. In this paper, the behavior of tunnels (underground structures) with different thickness of sand layer and moisture content under surface explosion are investigated by finite element method (FEM). Numerical results indicate that with increasing of sand layer thickness and moisture, the effect of surface explosions on the underground structures is decreased.

Keywords: FEM; sand layer; surface blasting; underground structures.

INTRODUCTION

A surface burst explosion will occur, when the detonation is located close to or on the ground, so that the initial shock is amplified at the point of detonation due to the ground reflections. The charge detonates, as it comes in contact with the ground and the blast wave is propagated with a hemispherical wave front. The initial wave of the explosion is reflected and reinforced by the ground surface to produce a reflected wave (UFC, 2008).

A comparison of these parameters with those of free-air explosions indicate that, at a given distance from a detonation, giving the same weight of explosive, all the parameters of the surface burst environment are larger than those for the free-air environment (UFC, 2008). For a conservative design, surface burst is considered the worst of the three types of blast. As a result, the charge weight of the explosive material under consideration is increased by the required factor of safety (Olarewaju *et al*., 2011). UFC (2008) allows for an increase of 20%.

A lot of work has been done on dynamic soil-structure interaction, mainly for linear, homogeneous, and semi-infinite half space. The response of elastic half space was first carried out by Lamb (Lamb, 1904). It was established that softer soils have lower natural frequency, while hard clays have less natural frequency than sand stones (Olarewaju *et al*., 2010).

Due to the significant development of numerical methods in recent decades, the effects of explosion on underground structures can be studied with high precision. Some numerical analysis studies are GUI (2006) and Nagy *et al*.(2009). Smith & Hetherington (1994) and Boulson (2003) have done extensive research related to the explosion in the soil. The results led to gain ground shock parameters and relationships. Zimmie *et al*., (2010) investigated the explosive effects on tunnels by using physical modeling. The results of their tests indicated that significant strain can be induced on underground structures due to explosions on the ground surface. American army regulations are approved by most engineers for underground explosions and their relationship is used for design and calculation of ground shock parameters (TM5, 1986).

Since sand layer is effective in reducing ground motion energy with high-frequency, the sand layer can reduce vibrations and structural damage caused by high-frequency of surface and subsurface explosion (Chengqing, 2004).

Various parameters, including the depth and weight of explosive charge, soil properties, and relative location of the buried structure to the explosive charge affect the structural performance of buried structures. In this paper, the influence of sand layer thickness and moisture due to surface blasting on underground structures is studied by FEM (PLAXIS software).

NUMERICAL ANALYSIS

PLAXIS software is used for dynamic analysis. Absorbing (viscous) boundaries are used for dynamic analysis of underground structures. The overburden is considered 21 m and the tunnel radius is 2.5m. Figure 1 shows the geometry of the model and boundary conditions. In Table 1, mechanical properties of soil and in Table 2, tunnel lining properties are illustrated. In this paper Mohr-Coulomb criterion is used for soil layers.

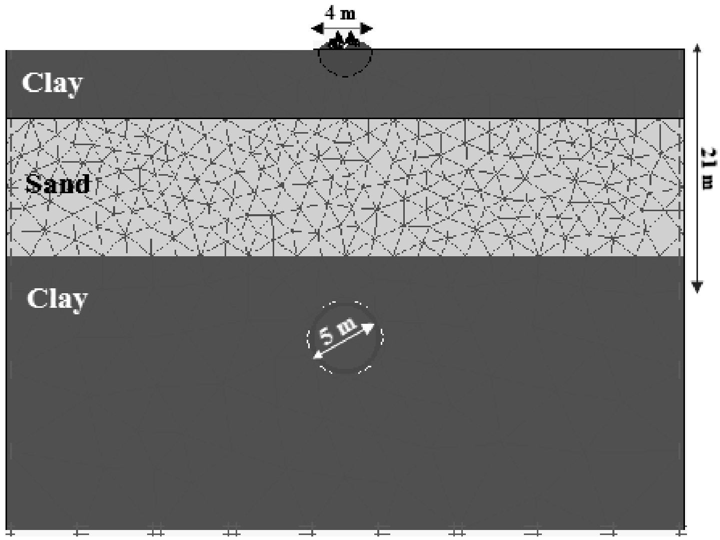

Fig. 1. Numerical model (geometry and boundary conditions)

Table 1. Soil mechanics parameters for different layers

Parameter	Unsaturated Density (γ_{unsat})	Saturated Density (γ_{sat})	Poisson's Ratio (ν)	Elastic Modulus (Es)	Friction Angle (φ)	Cohesion
Unit	kN/m^3	kN/m^3	-	MPa	degree	kN/m^2
Clay	15	19	0.4	160	0	50
Sand	17	20	0.3	324	45	0

Table 2. Tunnel lining parameters

Parameter	Density (γ)	Elastic Modulus (E_l)	Poisson's Ratio (ν)	Thickness
Unit	kN/m^3	GPa	-	cm
Value	25	25	0.15	25

APPLYING EXPLOSION LOAD

PLAXIS software cannot directly simulate explosion. However, dynamic load is applied by distribution of load on the border of explosion hole. To calculate the dimensions of the hole, explosion and stress are applied to its borders, by using empirical relations presented by America's Army (TM, 1986).

Peak particle velocity and peak stress are related by:

$$P_0 = \rho \, C_s \, V_r^{max} \tag{1}$$

Where, C_s is seismic velocity (m/s), ρ is soil density (kg/m^3) and V_r^{max} is maximum particle velocity (m/s). Maximum particle velocity is calculated by:

$$V_r^{max} = 48.8 f_c \left(\frac{2.52R}{w^{1/3}} \right)^{-n} \quad (2)$$

Where, f_c is coupling coefficient, R distance from the center of explosion and n wave attenuation coefficient. According to Figure 2, fc is considered 0.4.

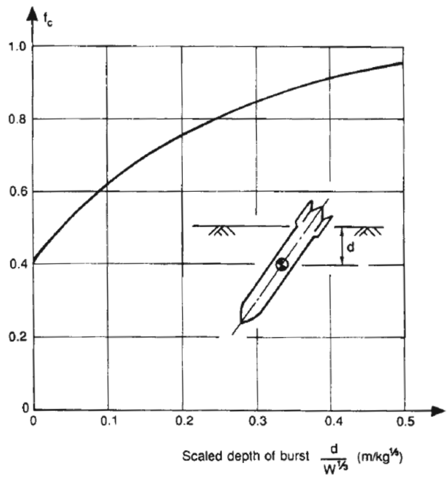

Fig. 2. Dependence of coupling factor on scaled depth of burst (Schmidt & Holsapple, 1980)

The accrual duration of the positive pressure phase is replaced by a fictitious positive duration t_d which is a function of the total positive impulse and the peak pressure:

$$t_d = \frac{2i_0}{P_0} \quad (3)$$

Where i_0 is special momentum and it is calculated by:

$$i_0 = \rho C x \quad (4)$$

Where x is maximum particle displacement of soil for buried and semi-buried structures that is related to:

$$\frac{x}{w^{1/3}} = 60 * \frac{f_c}{C} \left(\frac{2.52R}{w^{1/3}} \right)^{1-n} \quad (5)$$

The above relationships for the equivalent triangular pulse are applicable to the incident pressures as well as the reflected blast pressures (TM5, 1986).

Based on experimental and numerical studies, explosion hole diameter (d) is obtained by using the following equation (Ambrosini *et al.*, 2004):

$$d=0.65w^{1/3} \pm 5\% \tag{6}$$

For preliminary design considerations, Table 3 is suggested to be used in selecting the seismic velocity, acoustic impedance, and attenuation coefficients.

Table 3. Soil properties for ground shock parameters (Krauthammer, 2008)

Material Description	Seismic Velocity (fps)	Acoustic Impedance (psi/fps)	Attenuation Coefficient
Loose, dry sands and gravels with low relative density	600	12	3-3.25
Sandy loam, loess, dry sands, and backfill	1000	22	2.75
Dense sand with high relative density	1600	44	2.5
Wet sandy clay with air voids (greater than 4 percent)	1800	48	2.5
Saturated sandy clays and sands with small amount of air voids (less than 1 percent)	5000	130	2.25-2.5
Heavy saturated clays and clay shale	>5000	150-180	1.5

In this paper, 400 Kg TNT is used for the calculation. Figure 3 shows explosion loading diagram. The peak stress is considered at the start of explosion (TM5, 1986).

VERIFICATION METHOD

Some simple models with 4 soil types (very loose, loose, dense and very dense sand) are run for software verification. Hole radius is considered 2.3 m (based on equation 6), weight of explosives 50 kg TNT and seismic wave velocity 1000 (m/s). Figure 3 shows explosion loading chart for sand. In Figures 4 and 5, numerical results (displacement and velocity) are compared with TM5-1300 regulations for four soil types. According to Figures 4 and 5, America's Army regulation results are in good agreement with numerical results.

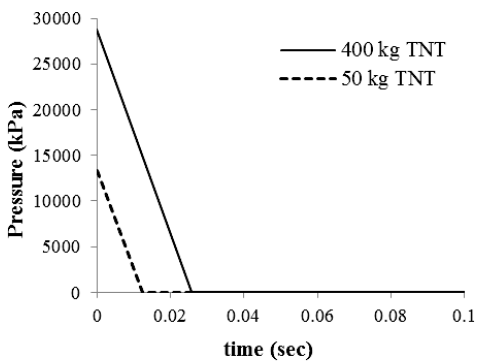

Fig. 3. Explosion loading chart for verification analysis

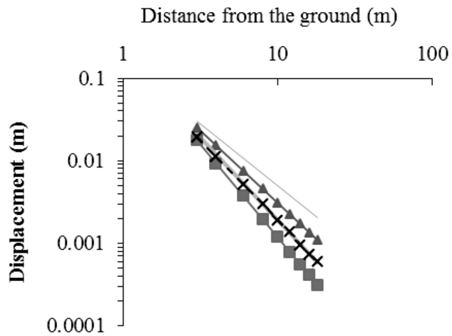

Fig. 4. Displacement- distance from the ground chart

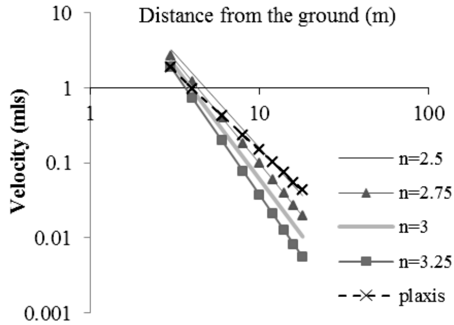

Fig. 5. Velocity- distance from the ground chart

RESULTS

Effect of sand layer thickness

In order to investigate the effect of sand layer thickness on tunnel dynamic response, 5 different sand layer thicknesses (0, 2.5, 5, 7.5 and 10 m) are considered. Crown point of tunnel is considered as target point; then displacement, velocity, and acceleration are calculated for target point.

Figure 6 shows displacement history for different scenarios. With increasing of the sand layer thickness, the displacement change is evident in the tunnel crown. Maximum displacement is reduced from 31 cm for the parts without sand layer to 20 cm for 10 m thickness with sand layer. Figures 7 and 8 show velocity and acceleration histories of zero and 10 m sand layer. According these figures, maximum velocity is reduced from 10.5 to 6 m/s and maximum acceleration from 1490 to 514 m/s^2. Figures 9 and 10 show percent reduction of maximum displacement velocity and acceleration versus sand layer thickness. Based on Figures 9 and 10, maximum displacement, velocity and acceleration are reduced to 35, 42 and 60%, respectively.

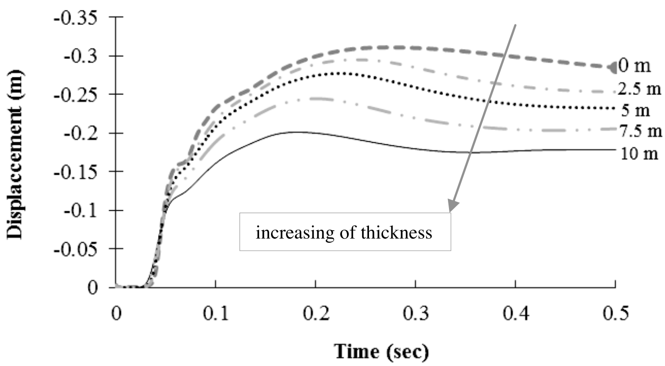

Fig. 6. Displacement time history versus sandy layer thickness

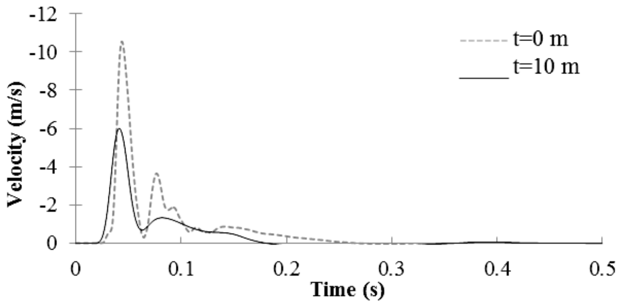

Fig. 7. Velocity time history versus sandy layer thickness

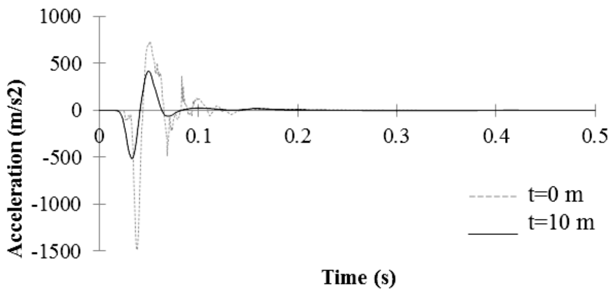

Fig. 8. Acceleration time history versus sandy layer thickness

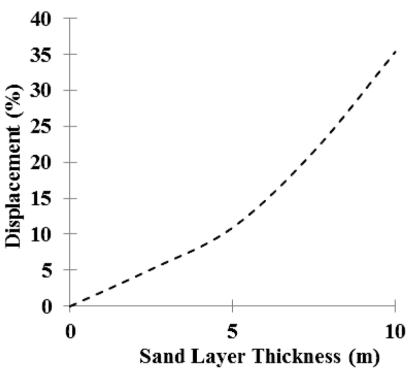

Fig. 9. Displacement reduction percent versus sand layer thickness

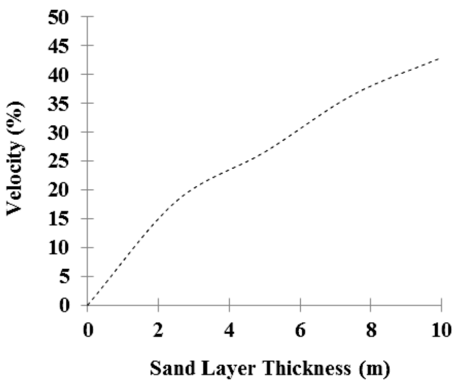

Fig. 10. Velocity reduction percent versus sand layer thickness

Moisture content of sand layer effect

Since the characteristic arrival time is inversely proportional to seismic velocity, explosions in high-velocity media, such as saturated clay will produce very short, high-frequency pulses with high accelerations and low displacements. On the other hand, detonations in dry and loose materials will produce ground motions of much longer duration and lower frequency (TM, 1986).

To evaluate the moisture content, groundwater level is changed in the sand layer. By taking the water level in quarter, half, three quarters and whole sand layer (saturated condition), the effects of moisture content on tunnel under explosion loading, in each sand layer is studied. Then, displacement, velocity and acceleration in target point are calculated. Figures 11, 12 and 13 show the history of displacement, velocity, and acceleration for sand layer with thickness equal to 5 m. According to these figures, parameters are decreased with increasing moisture content, so that the values of maximum displacement, velocity, and acceleration are decreased from 27.7 cm, 7.73 m/s and 725 m/s^2 to 14.2 cm, 3.57 m/s and 365 m/s^2, respectively. Figures 14, 15 and 16 present the percentage of reduction of maximum values for target point, in sand layers with different thickness. For example, if thickness of the sand layer is 5.7 meters, with increasing moisture content to saturated condition, maximum displacement in target point will be reduced approximately by 55%. In other words, with increasing moisture content (increase in water level), explosion energy is damped and damages to underground structures is reduced.

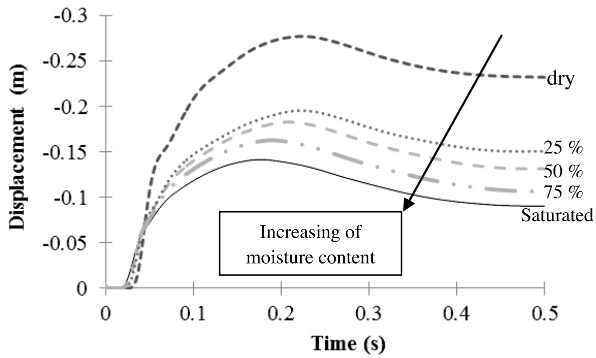

Fig. 11. Displacement time history versus sandy layer moisture content

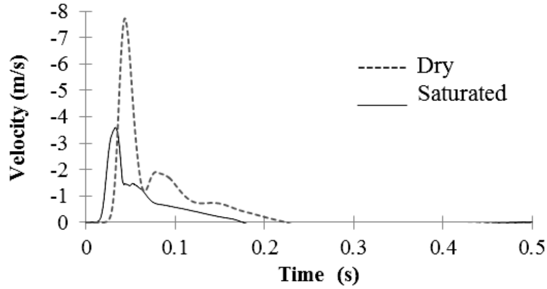

Fig. 12. Velocity time history versus sandy layer moisture content

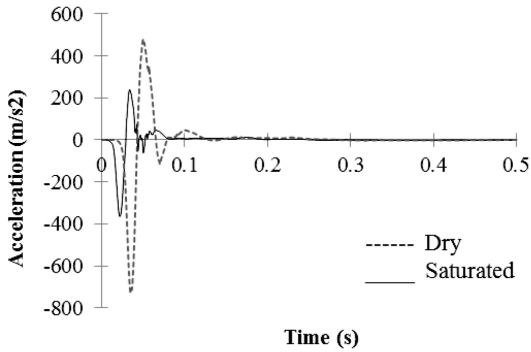

Fig. 13. Acceleration time history versus sandy layer moisture content

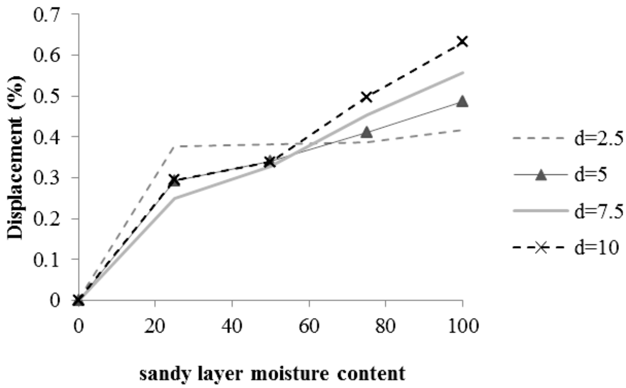

Fig. 14. Displacement reduction percent versus sandy layer moisture content

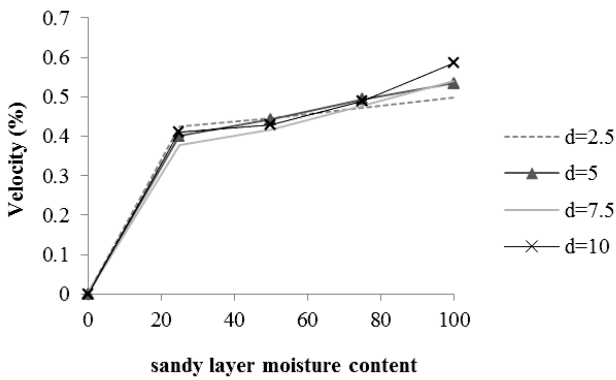

Fig. 15. Velocity reduction percent versus sandy layer moisture content

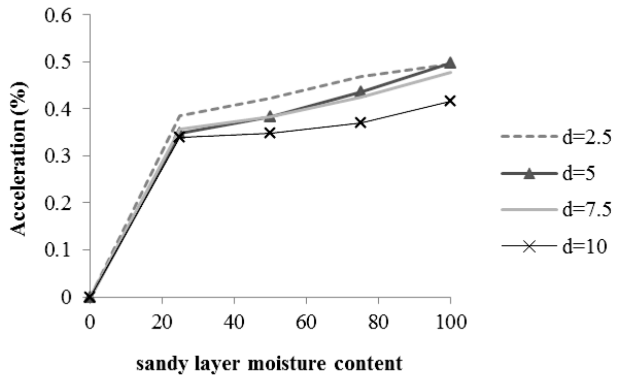

Fig. 16. Acceleration reduction percent versus sandy layer moisture content

CONCLUSION

In this paper, the effect of sand layer (thickness and the percentage of moisture content) on the behavior of underground structures, due to the surface blast loads is analyzed by using the PLAXIS 2D software. The results imply that sand layer is a suitable material for reducing the explosive effects. Increasing the sand layer thickness and moisture contributes to reduction of the effects of surface explosions. By increasing thickness of sand layer and moisture content, maximum values of displacement, velocity, and acceleration are decreased. The maximum displacement, velocity and acceleration are reduced about 35, 45 and 40 percent by increasing thickness of sand layer to 10 m. By applying moisture content to sand layer, these values are reduced approximately to 30, 40 and 35 percent, respectively. In other words, by increasing moisture content and sand layer thickness, explosion energy is damped and damages to underground structures are reduced.

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