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The Effects of Tunnel Excavation on the Seismic Response of Ground Surface Using Finite Difference Method

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ABSTRACT: Increasing urban populations and creating traffic problems, the use of the underground spaces in the transportation is inevitable. Recent studies have shown that seismic response of ground on tunnels can differ from free field movement during earthquake and change the model of propagation of seismic waves. However, these effects have not been used in the seismic standards for the design of surface structures. In this research, using the finite difference method and FLAC 2D software, the effects of tunneling on earthquake amplification on the surface has been studied. For this purpose, the variation of the shear wave velocity of the soil under harmonic waves by different frequencies and amplitudes in both forms of the presence of a tunnel and in the free field have been investigated. The results of the studies showed that soil hardness and frequency of waves have a significant effect on the site response, and can increase the acceleration of the surface in harmonic waves to about 1.3 and with the acceleration of the Bam earthquake to about 1.7 times. Whereas, the presence of tunnel does not affect at longer distances of 15 times its radius. The coefficients obtained the site response can be used in seismic zoning of urban areas and for the design of seismic structures in the area affected by the tunnel.

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1- Introduction

Underground tunnels, causing static and dynamic changes in the ground. Many researchers investigated this issue with different methods of physical modeling, numerical and analytical methods. However, studies on the effects of underground structures in the seismic response are still limited. The first study was done by physical modeling method to investigate the effect of underground structure by Abuhajar et al. [1]. They studied the effect of box-shaped underground canals on the acceleration response of soil by centrifugal tests. Smerzini et al. [2] studied the effect of underground cavities on the seismic response due to the propagation of SH waves by analytical method. Lee et al. [3] examined the seismic behavior of shallow semicircular foundation the seismicity of the near-surface rugged, semi-conductor tracks near the surface above the top of a covered tunnel tunnel. In the research by Tsaur and Chang [4] diffraction [1]SH waves in collision with tunnels have been investigated. Sica et al. [5] performed a numerical study using a [2]FEM code QUAD4-M to investigate the effect of underground cavities on the ground motion amplification along the free surface of a hill. Their model was inspired by a real case, Castelnuovo (Italy), which experienced huge damage after the 2009 Abruzzo earthquake. The subsoil of Castelnuovo was characterized by several underground cavities. The numerical study highlighted that the presence of multiple shallow cavities affects the ground amplification along the free surface of the hill and, hence, cannot be ignored. They proposed that the effect of underground cavities on the ground motion amplification effect should be properly considered for both micro-zonation studies and the correct determination of the seismic actions on specific buildings. Alielahi et al [6, 7] researched about maximal stresses and distribution patterns of the tunnel section under the P- and SV-waves are thoroughly studied. Which should prove useful to the design of no lining and with lining underground tunnels. Present an advanced formulation of a time-domain 2-D boundary element method (BEM). They extended an efficient algorithm to analyze the seismic response of underground structures and their effect on the surface canyon and on the flat free surface. Yiouta-Mitra et al. [8] performed a series of parametric analyses to quantify the effects of parameters H/a, x/a, dimensionless frequency and flexibility ratio for circular tunnels using viscoelastic numerical studies. The parametric studies were conducted for both unlined and lined circular tunnels and found that underground spaces and structures affected the acceleration of nearby ground. Baziar et al. [9-11] investigate the effect of square tunnel on acceleration response at ground using centrifuge and numerical simulations. In the present study,

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1 shear horizontal
2 Finite Element Method

using the [1]FLAC software based on the finite difference method, the effects of various parameters such as shear wave velocity, frequency of waves, tunnel depth on wave magnification at ground were investigated and the maximum acceleration magnification coefficients for seismic design of surface structures were proposed.

2- Methodology

Using Flac-2D software, modeling has been done to get the site response in conditions with the presence of the tunnel and the free field. The dimensions of the model are 180 meters wide and 50 meters deep. Also the mesh dimensions are obtained using the results of the Kuhlemeyer and Lysmer [12] investigations. For precision, four-sided flat-stratified elements with a maximum dimension of one meter were used. The model shown in Figure 1.

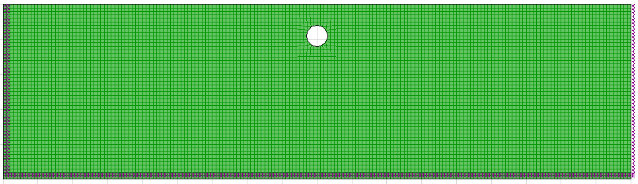

Figure 1. An example of a numerical model circular tunnel and the environment

The analysis follows the Mohr-Coulomb model. In modeling the soil cohesion and friction coefficient are assumed to be 15 and 30 kN/m^2 and to get the bulk modulus and shear modulus, the relations ($G=\rho\times VS^2$) and ($B=E/3(1-2\nu)$) is used. Properties of soil provided in Table1. The tunnel lining is assumed with modulus of elasticity 24 MPa and a Poisson coefficient 0.2 and in all models, the lining thickness is 30cm and the diameter is 6 m.

Table 1. Properties of soil

Soil Type	Shear wave shear velocity (m/s)	Poisson υ	specific gravity γ (kPa)	shear modulus G (MPa)
IV-III	175	0.35	16	4.9
III	250	0.35	16.5	103
III-II	375	0.3	17	239
II	500	0.3	17.5	438
II-I	750	0.3	17.5	984

3- Results and Discussion

Harmonic waves with different periods are applied to the model, and acceleration and velocity magnitudes are obtained at ground. The maximum acceleration magnitude occurred at the center of the tunnel and at a period of p=0.25 (s). In this case, the magnification was 1.3 times .The near frequency of the input wave to the natural frequency is due to increasing the amplitude on the surface. The shear wave of the soil, the depth and diameter's tunnel was effected to magnification wave.

4- Conclusions

The amplification ratio at the ground surface were dependent on period of wave, dimensionless depth (h/a) parameters. The effect of the tunnel on the seismic ground surface response decreases or becomes insignificant by increasing the buried depth of the cavity. Tunnel effect on the ground surface acceleration was evident at the distance of fifteen times the tunnel radius from the tunnel center at both side. Magnification patterns in harmonic waves are different from acceleration history. This influence increases the acceleration up to 1.7 times in Bam earthquake and 1.3 times in harmonic waves. This increment can change the design acceleration from suggested code (0.35 g for the very height risk area) to 0.6 g on center of tunnel at ground surface. The maximum impact of the tunnel on the velocity and acceleration of the ground surface at X/a=0 and X/a=2 distances in the period from 0.1 to 1.5 second and in the longer periods, the effect of the tunnel on the magnification will be very low due to the distance from the natural frequency of the model.

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