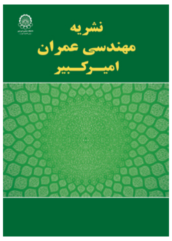

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Seismic Analysis of Rectangular Tunnels (Cut and Cover Method), Soil-Structure Interaction

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ABSTRACT: One of the tunneling methods is cut and cover method, in which the excavation starts from the ground surface and deep in the ground, then a concrete box is made as a tunnel. Thus in this method, the cross section of the tunnel is not circular but rectangular. The aim of this paper is seismic analysis of rectangular tunnels. For a special accelerogram, tunnel geometry, depth of overburden and ground conditions are the three main factors affecting the dynamic behavior of the tunnels. By numerical methods and by assuming the plane strain condition, models of this type of tunnels were analyzed. According to the results, the maximum internal forces that are generated in the tunnel lining and the stress concentration are at the corners of the cross section of rectangular tunnel. In seismic mode, the internal forces of concrete lining are several times of static mode. In this situation, the ground surface settlement profiles are asymmetric and the settlement is greater than the static mode. In tunnels with large width, in 2D cases, if a column is placed in the middle of span, the ground settlement, bending moment and shear forces is decreased in comparison with 1 span tunnel with the same dimension.

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1- Introduction

The cut-and-cover method is one of the ways used for construction of tunnels. The applicability of this method emerges when first the tunnel is of surface type and second there is no limitation on the ground in terms of excavation. In this case, excavation is started off the ground level followed by construction of a thick concrete slab in the desired depth as the tunnel floor. This is next followed by construction of the walls and concrete ceiling of the tunnel where eventually through embankment on it, the tunnel is buried under the ground. In this way, the tunnel takes a floor with a rectangular section.

Ovaling deformation of circular tunnels or racking deformation of rectangular tunnels in response to shear stresses can be analyzed by different models. They include nonlinear complex analyses and those that consider the soil-structure interactions. Simplified pseudo-static analyses can consider or not consider the soil-structure interactions. Neglecting the soil-structure interactions means the tunnel structure follows the deformation of the ground free field [1,4]. However, this simplification leads to uncertain results, especially when the structure is more flexible than its surrounding environment [2]. For this reason, several analytical and numerical methods have been proposed for considering the soil-structure interaction in the simplified models, most of which are applicable to circular tunnels [4, 8]. With respect to rectangular tunnels which are also the discussed topic in this paper, several methods have been presented [2,5-7]. The assumptions common across all of the simplified analyses are:

1. Consideration of plane strain conditions for the model.
2. Assumption of linear elastic deformation for the structure and ground.
3. Assumption of pseudo-static analysis, though except for the method proposed by Wang [1993].

This paper deals with the seismic analysis of rectangular surface tunnels with the aim of investigating the seismic behavior of the tunnel by taking soil-structure interaction into account. The dimensions of the tunnel, the depth of tunnel placement, different layering of the soil around the tunnel in relation to virgin soil, the effective factors influencing the ground surface settlement and the internal forces developed in the tunnel lining are investigated in this research. In tunneling by the cut-and-cover method, the soil layering becomes inevitably weaker than and different from that of natural ground soil around and on the tunnel ceiling up to the ground level. This issue becomes another effective factor in seismic behavior and thus is further studied in this research. Modeling has been done by FLAC software two-dimensionally and under plane strain conditions. It is assumed that the environment uses sandy soil with a full elasto-plastic behavior model and is a function of Mohr-Coulomb failure criterion. Next, the procedure of modeling of the input wave has been provided for seismic analysis with Tabas selective accelerogram. This is followed by the examining the procedure of determination of mechanical properties of the ground and dynamic parameters including attenuation, etc.

2- The procedure of modeling

The accelerogram used for these analyses is the Tabas seismic accelerogram with maximum acceleration of 0.83 g and

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duration of 32.82 s. Through the program written in the form of commands of FISH functions, the accelerogram has been modified followed by calculation of the speeds obtained from the earthquake acceleration record.
The model geometry includes an environment with 150 m wide and high. According to the sensitivity analysis conducted on the network size and validation, to achieve full shape of the tunnel and receive results with a high accuracy, the network size has been chosen as 1×1 m^2 and 2×2 m^2 in regions away from the tunnel with the region's dimensions being 30×52 m^2. The properties assumed and obtained for the soil environment are provided in Tables 1 and 2, respectively. In these tables, v_s is Poisson coefficient, e is the porosity ratio, C is adhesion, γ_s is the specific weight, K_0 is the lateral pressure coefficient of soil, E_s is the elasticity module and K_s is the bulk (volume) module of the soil.
After introduction of materials properties, the boundary conditions are applied to the model. The lower horizontal boundary is applied at both directions x and y, while the lateral vertical boundaries are only applied along x direction. After exertion of boundary conditions, the problem is solved elastically and under the preliminary equilibrium conditions (Note that no excavation is carried out at this stage). After provision of the preliminary equilibrium, the tunnel is excavated and the tunnel lining is installed. For lining, the liner element has been used which is able to tolerate the axial, bending and shear forces. The mechanical properties of the concrete lining of the tunnel used in the modeling are provided in Table 3.
In the modeling, installment of tunnel lining is performed using the elements of the interface of the structure and the soil.
After determination of attenuation, the dynamic boundary conditions are applied to the system. For this purpose, the conditions of free field and laminar field are defined for lateral and lower boundaries, respectively in order to minimize the effect of reflection of waves. With definition of the viscous boundary, it is essential that the wave model be in the form of shear stress [12]. By applying the tension wave, solving of the problem dynamically starts.

Table 1. The properties assumed for the soil environment

K_0	0.4
γ_s (kg/m^3)	2100
C (kg/m^2)	0
φ (°)	35
e	0.3
v_s	0.25

Table 2. The mechanical properties of soil obtained from the relations

K_s (kPa)	9.2e5
E_s (kPa)	1.4e6
G_s (kPa)	5.5e5

3- Conclusion

In this paper, the response of rectangular surface tunnels was analyzed against seismic loads in which the factors affecting the response of tunnels have been categorized into four groups: 1. The tunnel geometry, 2. Existence of a wall in the middle of the span of wide tunnels, 3. The difference between the material of the soil surrounding the tunnel with the main environment (Fig. 1) and 4. The tunnel depth. The effect of each of these factors has been investigated individually on the internal forces developed inside the tunnel lining and the surface settlement of the ground in response to seismic loads and further compared with the static state. Note that the internal forces considered in the dynamic analyses are related to the maximum of these forces during application of the accelerogram. However, the demonstrated surface settlement profiles are intended for the end of the dynamic analysis time. For conductance of the seismic analysis, two-dimensional models have been used under the assumption of plane strain followed by application of earthquake accelerogram to the model. According to the results:

- In a seismic state, the forces and moments developed in the concrete lining of the tunnel increase up to several times in comparison with the static state. On average, for a tunnel with different dimensions and placement depths, the axial force of the seismic state, bending moment and shear force increase up to 3, 5.6, and 3.2 times the static state, respectively.
- In the seismic state, the surface settlement profile of the ground becomes asymmetrical, where the extent of settlement increases in comparison with the static state. In this case, the maximum settlement of the profile can reach 8 times that of the static state. Furthermore, in the seismic state, the ground undergoes a kind of distortion and develops a wave-like curvature.
- By increasing the tunnel width in both static and seismic states, the values of internal forces increase. For example, if the tunnel width increases from 8 to 16 m, then the internal forces develop up to 4 times and 1.6 times on average in the static and dynamic states, respectively. By increasing the tunnel height, increasing of internal forces happens as well, but the rate of growth in the static state is lower than that of the seismic state. By increasing of dimensions, the pressure of

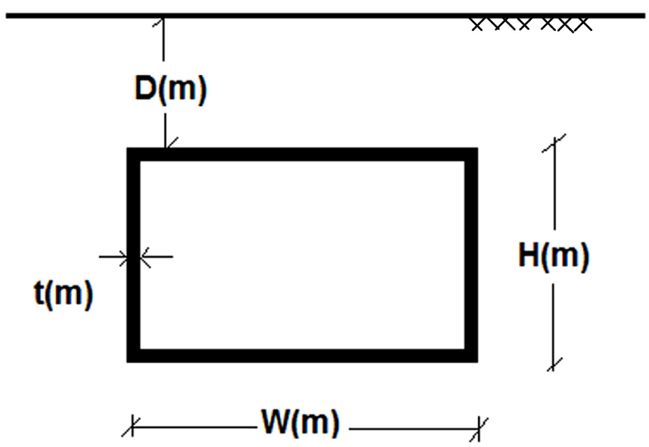

Fig. 1. Demonstration of the parameters used in the rectangular tunnel

Table 3. Variations in the bending moment of the lining with changes in the tunnel width

Bending moment in dynamic mode to static mode	Bending moment in dynamic mode (*kN-m*)	Bending moment in static mode (*kN-m*)	*t* (*m*)	*D* (*m*)	*H* (*m*)	*W* (*m*)
7.3	3408	467.9	1	10	6	8
5.6	4300	761.8	1	10	6	10
4.5	5591	1234	1	10	6	12
2.6	5100	1935	1	10	6	14
2.2	6196	2857	1	10	6	16

soil on the lining grows resulting in increased internal forces.

• By increasing of the lining thickness, due to increased stiffness, the internal forces also increase, but the rate of growth is far less in the static state. According to the results, if the lining thickness is increased from 0.5 to 1 m, the internal forces are increased 1.1 and 1.6 times on average in the static and seismic states, respectively. The thickness and the surface settlement of the ground are inversely related.

• In tunnels with a high width (10 m and above), if one column is added in the middle of the tunnel span, the bending moment and shear force of the lining will be modified. It means that if a tunnel 10 m wide is changed into a two-span tunnel by addition of a column, the bending moment and shear force of the lining are reduced up to 40% and 25% on average in static and seismic states, respectively. In addition, existence of the middle concrete wall has a crucial role in reducing the ground surface settlement.

• With increasing the depth of tunnel, the pressure on the tunnel is increased and leading to increased internal forces in both static and seismic states. For example, if the tunnel depth is increased from 5 to 15 m, the value of internal forces increases 1.6 times in both seismic and static states.

• If the soil surrounding the tunnel has a lower elasticity module and stiffness in comparison with the main soil, then lower soil pressure is exerted on the tunnel walls and thus the internal forces developed in the lining lessen. For instance, if the elasticity module of the soil surrounding the tunnel diminishes 60% in comparison with that of the main soil, then the internal forces also decline up to 3% and 2%, on average in the static and seismic states, respectively in comparison with the case when the environment is totally homogenous. On the other hand, when the soil surrounding the tunnels weakens, the ground surface settlement grows.

• The top and bottom corners of rectangular tunnels are the locations for concentration of forces and tension. This issue should be taken into consideration when designing a lining for the tunnel.

Table 3 along with Figs. 2 and 3 indicate the variations in the bending moment and settlement profiles, respectively for the changes in the tunnel width.

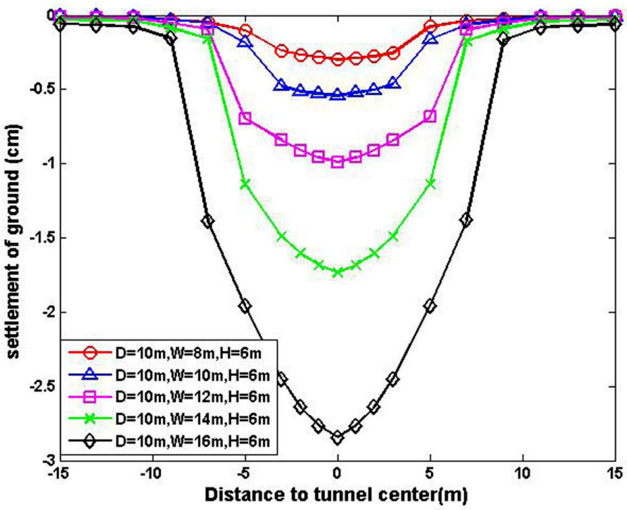

Fig. 2. The ground surface settlement profiles for different widths of the tunnel in the static state

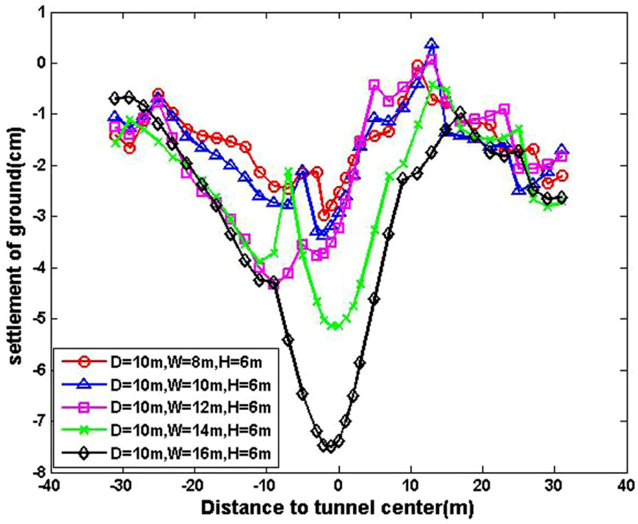

Fig. 3. The ground surface settlement profiles for different widths of the tunnel in the seismic state

References

[1] A., Hendron; G., Fernandez; Dynamic and Static Design Considerations for Underground Chambers, *Seismic Design of Embankments and Caverns, American Society*

of Civil Engineers, 1983.

[2] H., Huo; A., Bobet; G., Fernandez; J., Ramirez; Analytical Solution for Deep Rectangular Structures Subjected to Far-field Shear Stresses, *Tunnelling and Underground Space Technology*, Vol. 21, pp. 613-625, 2006.

[3] ITASCA, FLAC2D Version 5; Fast Lagrangian Analysis of Continua in 2-Dimensions, *ITASCA Consulting Group Inc.*, 2005.

[4] J. L., Merritt; J. E., Monsees; A. J., Hendron; Seismic Design of Underground Structures, *Proceedings of the 1985 Rapid Excavation Tunneling Conference*, Vol. 1, pp. 104-131, 1985.

[5] J., Penzien; C., Wu; Stresses in Linings of Bored Tunnels, *Int. J. Earthquake Eng. Struct. Dyn.*, Vol. 27, pp. 283-300, 1998.

[6] J., Penzien; Seismically-induced Racking of Tunnel Linings, *Int. J. Earthquake Eng. Struct. Dyn.*, Vol. 29, pp. 683-691, 2000.

[7] J. N., Wang; Seismic Design of Tunnels: A State-of-the-Art, Approach, Monograph, Monograph 7, Parsons, *Brinckerhoff, Quade and Douglas Inc.*, New York, 1993.

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