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# Assessment of the Drain Conditions on Variations of the Pore Pressure in Surrounding Soil of the Tunnel

M.Azadi[a,*], S.M.Mir Mohammad Hosseini[b], S.M.Nasimifar[c], M.Pouranian[c]

[a] *Islamic Azad University, Qazvin Branch, Qazvin, Iran*

[b] *Amirkabir University of Technology, Tehran, Iran*

[c] *Civil Engineering, Sharif University of Technology, Tehran, Iran*

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**Abstract**

Excess pore pressure under seismic loadings has always been a main concern in geotechnical engineering practices. The phenomenon in soil can cause an effective stress and hence cause the shear strength of the soil to decrease considerably and large deformations to occur in the area. Generally, increases in pore pressure occur in un-drained conditions. If it is formed, its consequences decrease seriously. There are several reports on devastations caused by excess pore pressure in the surrounding soil of the underground structures. As stresses and deformations of the tunnel lining increase, the surrounding soil of the tunnel is liquefied and large deformations become observable. If an increase in the pore pressure occurs in the surrounding soil of the tunnel, which is an improvement of the surrounding area of the tunnel, then stresses and deformations should be set on the allowable limit. Therefore, evaluation of excessive pore pressure effects on the tunnel lining can be regarded as an important issue and this paper is designed to focus on precisely this topic.

*Keywords*: Drain conditions; Tunnel, Pore pressure; Soft soil; Deformation

## 1. Introduction

The damages caused by excess pore pressure are divided into two groups: surface damages and underground-structure damages. Generally, the first case is visible after the seismic loadings, about which large amounts of research have been performed. But in the second group, lack of these occurrences and investigation into problems can cause the underground-structure damages to be assessed less.

Damages to small life lines were observed first in the Nigata earthquake (1964) [1]. Since then, earthquake effects on underground structures have become an important issue and, as a result, several studies have been carried out about dynamic analyses of the underground structures. In the Kobe earthquake (1995), most devastation happened in several urban subway systems, such as the Daikai station [2]. The Twain earthquake (1999), Duzce earthquake in Turkey (1999), Tangshan earthquake in China (1976) and Loma Prieta earthquake in America (1989) are some other examples of damages to underground structures [3-6].

Increasing the pore pressure under the undrained conditions may cause damages to the underground structures. As the amount of excess pore pressure reaches effective stress resulting from the first overburden, liquefaction occurs. After being exposed to the soil liquefaction the underground structure will be damaged. The damages include uplift, lateral spreading and the settlement of structures (Liu and Song, 2005). Not many studies have been conducted on damages to large underground structures. Regarding the case, Schmidt and Hashash report some California tunnels in the Loma prieta earthquake (1989) became susceptible to buoyancy [6]. Some researches [7-12], such as Chou's, have focused on this matter [7]. They assessed the effect of soil liquefaction on shield tunnels in their studies.

Sometimes, during the earthquakes, non-liquefiable soils show large and asymmetric deformations. This

*Corresponding Author Email: azadi@qiau.ac.ir

phenomenon occurs adjacent to rivers, seas and oceans. The geological investigations in these areas show that the new deformations and forces happen in this region, although the surrounding soils have a good strength, due to undrained conditions of soil.

According to field evidence, linear structures such as tunnels may be destroyed by raising this pressure. Thus, this phenomenon should be taken into consideration in the designing stage of tunnels. There are several reports on devastations caused by increasing the pore pressure in the surrounding soil of the underground structures. Nigata (1964), Nihonkai- ubuhC (1983), Luzon (1990), -iko Kushiro (1993) and odiakkoH -ikoNansei (1993) are some examples of the mentioned cases developed by some researchers in connection with the past major earthquakes [13-17]. In this regard, Liu and Song evaluated the effects of soil liquefaction on the underground structures [2]. Their research showed that the uplift pressure acted beneath the underground structures caused by increasing the pore pressure, and thereby induced the upward displacement of the structure as shown in fig. 1. The above results are in good agreement with those obtained by Khoshnodyan's researches on the impacts of the excess pore pressure on excavated tunnels in the soils [15] (fig. 2). Based on these researches, although the features of the loads do not change too much, the interior loads in underground structures are not the same when the surrounding soils are liquefied [15]. Thus, the drain conditions of the embedded structures are regarded as one of the most important reasons for damages to the underground structures during the soil liquefaction, and should be taken into consideration in the design of underground structures.

## 2. Modeling conditions

The study was conducted to assess the effect of drain conditions on variations of pore pressure. For this purpose, a tunnel is considered with 6 (m) interior diameter, the 30 (cm) thicknesses and elastic modulus of

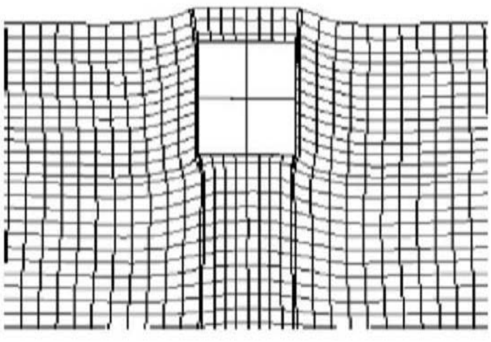

Fig. 1.Display of underground structure uplift due to the dynamic loading

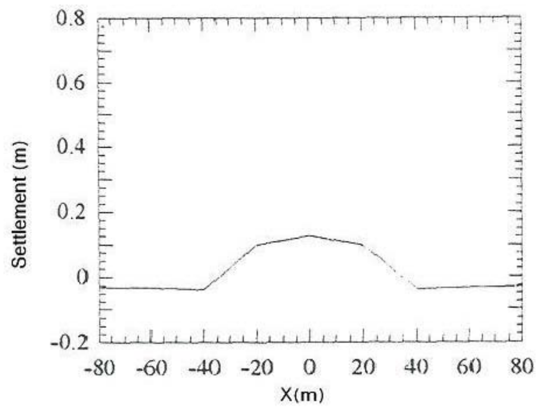


Fig. 2.Variation of surface deformation versus distance from the tunnel center

$2.236*10^7$ ($kN/m^2$) which its center is located 10 (m) below the ground surface (see fig 3). To assess the drain conditions effect, it is necessary for the soil to be saturated. Thus, the water table is considered to be at the ground surface. General properties of soil are according to geotechnical parameters of VELACS project [2, 15] and are shown in fig. 3.

Dynamic load is generally a wave with amplitude of 0.1g and a frequency of 1 (Hz) that is defined under the model as follow:

$$\ddot{u}_g = \sin(2\pi t) \quad (1)$$

Where $\ddot{u}_g$ is the acceleration from bedrock to the ground surface, t is the Duration of dynamic load that also is considered 10 (s). This time is considered in such a way that the process of the analyses leads to a steady state and the impact of the dynamic load are seen completely.

The simulation model takes place in three stages. The first stage is static equilibrium in the area under drained and undrained conditions, in which the effect of drain conditions is assessed on variations of the tunnel lining forces under static loading. The second stage is the dynamic analysis, in which the effects of drain conditions are evaluated on variations of pore pressure under dynamic loading. Meanwhile, the damping ratio is 5% and free field conditions are considered for the dynamic

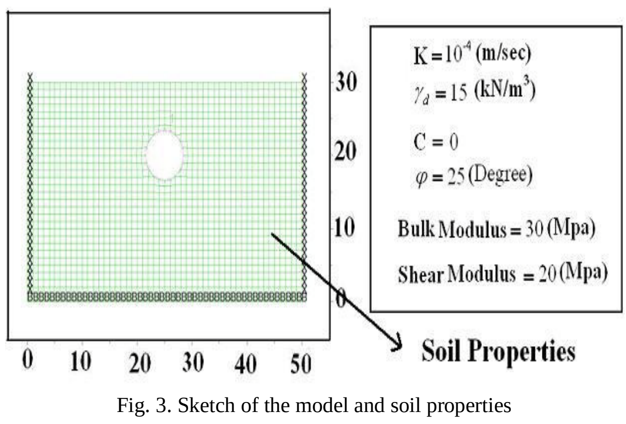


Fig. 3. Sketch of the model and soil properties

boundaries. In this condition, the reflection of waves in the model is prevented and the boundaries act as adsorbent boundaries. Finally, in the last stage the variation of the soil permeability is assessed that is a main parameter in the creation of drain conditions.

## 3. The effect of drain conditions on variations of the forces and deformations of the tunnel lining under static loading

Structures have a long life span; therefore, static analyses are generally performed for a drained condition. Thus, in this section, the effect of drain conditions is evaluated on variations of forces and deformations of the tunnel lining. For this purpose, in the evaluations, the soil parameters are considered constant and drain conditions are assessed.

Fig. 4 and 5 show the drain conditions versus bending moments and axial forces. According to these figures, changing the conditions from undrained to drained cause the bending moments and axial forces to decrease. Removing the excess pore pressure in drained conditions in comparison with the untrained condition is the reason for reduction.

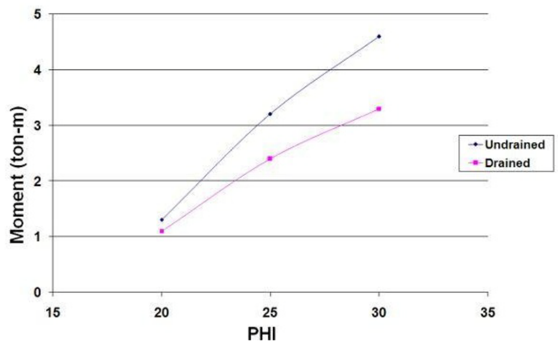


Fig. 4. Variations of bending moments versus friction angle (PHI) for drained and undrained conditions

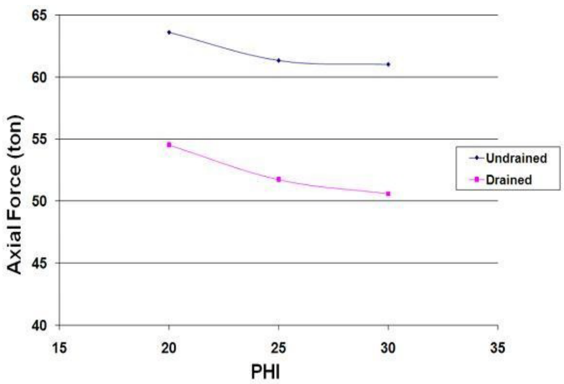


Fig. 5.Variations of axial forces versus friction angle (PHI) for drained and undrained conditions

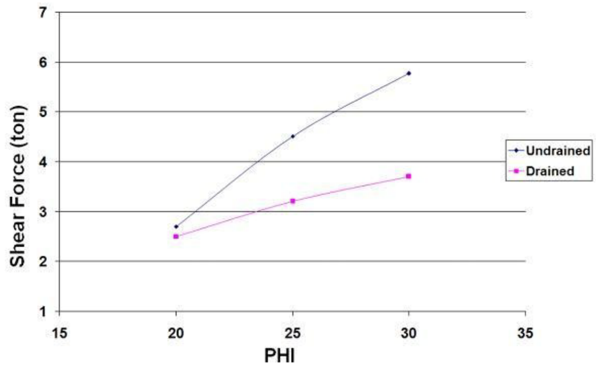


Fig. 6.Variations of shear forces versus friction angle (PHI) for drained and undrained conditions

Thus, fewer forces push the tunnel lining, and therefore deformation and interior forces of the tunnel lining decrease. In addition to that, it seems that raising the friction angle causes the bending moments and axial forces to increase for both conditions. This trend is also observed in the shear force. Fig. 6 illustrates varieties of shear forces in the tunnel lining versus friction angle for the two mentioned conditions. According to this figure, changing the drain conditions from undrained to drained causes shear forces to decrease similar to axial forces and bending moments.

On the basis of the carried-out analyses, deformations of the tunnel lining in the undrained condition are more than drained condition. Based on these analyses, the average deformations of the tunnel lining in the undrained and drained conditions are almost 11 (mm) and 4 (mm) respectively.

According to reached analyses about effect of drain conditions on forces and deformations variation of the tunnel lining, it can be found that if a soil specimen put under the static loading in two cases of undrained and drained conditions, forces and deformations of the tunnel lining rise because of increasing the pore pressure and decreasing the effective stress of soil in the undrained condition. It is necessary to mention that this topic is not consistent with the short-time and long-time design of structures, because soil parameters for undrained and drained conditions are different.

## 4. Effect of drain conditions on variations of pore pressure in dynamic analyses

Regarding the point that the earthquake takes a short time to occur, the conditions of an area is an undrained condition. Therefore, excess pore pressure is created in the area and it causes the exposure conditions to change and liquefaction to occur. But, after liquefaction, the condition varies to a drained condition and excess pore pressure dissipates. As a result, the liquefaction effects decrease significantly. Therefore, after liquefaction analyses with undrained condition, analyses have been performed for a drained condition. Fig. 7 shows raising the pore pressure for undrained condition. According to

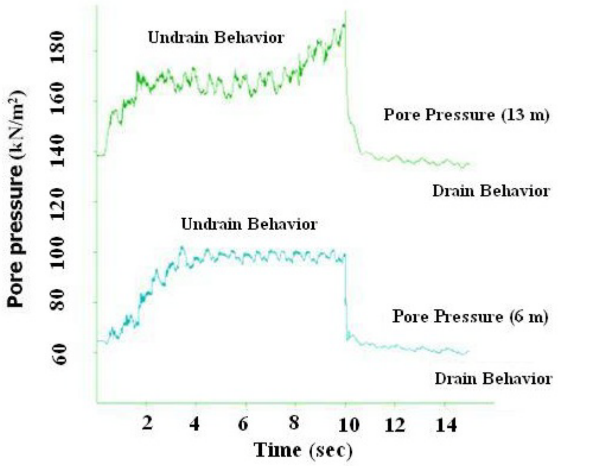


Fig. 7.Display of pore pressure variations in two points, upper depths of tunnel crown (at the depth of 6 m) and lower depths the tunnel (at the depths of 19 m) for drained and undrained conditions

this figure, the pore pressure decreases seriously after creation of drained condition. Regarding the analyses, structure uplift and surface heave also reduce extremely. Furthermore, forces and bending moment of the tunnel lining under dynamic loading (for drained condition) decrease about 10%.

## 5. Assessment of permeability effect under dynamic analyses

Pore pressure decreases as soil permeability increases, and it causes the forces of the tunnel lining to reduce. Studies show that increasing the soil permeability causes excess pore pressure and as a result, forces the tunnel lining to decrease. According to these studies, increasing the permeability from $10^{-4}$ (m/sec) to $10^{-3}$ (m/sec) causes the bending moments and shear forces to rise 16.2% and 0.3% respectively. Furthermore, tunnel uplift reduces almost 5%.

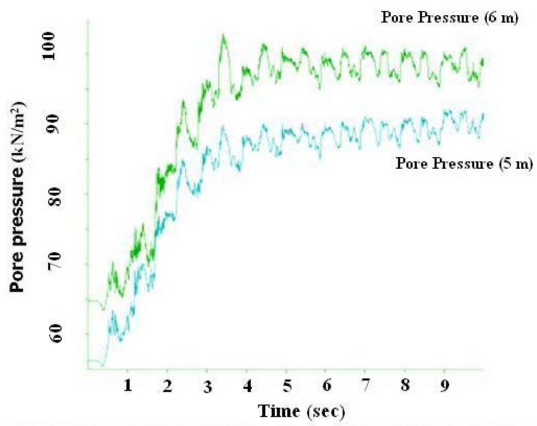


Fig. 8 Variations of pore pressure at the depths of 5 (m) and 6 (m) from ground surface (upper depths of tunnel crown, K= $10^{-4}$ m/s)

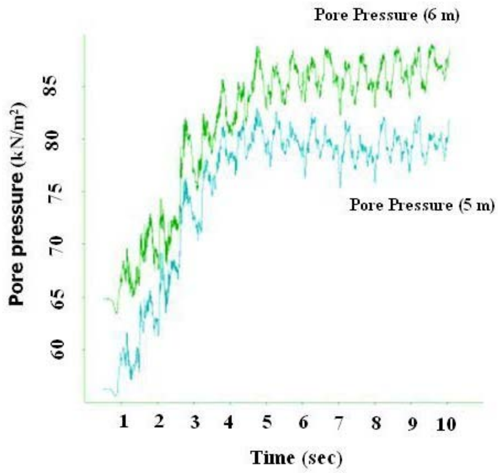


Fig. 9.Variations of pore pressure at the depths of 5 (m) and 6 (m) from ground surface (upper depths of tunnel crown, K= $10^{-3}$ m/s)

Fig. 8. displays variations of pore pressure for upper depths of tunnel crown and permeability of $10^{-4}$ (m/sec), and Fig. 9 displays these variations for permeability of $10^{-3}$ (m/sec). Apparently the pore pressure decreases when permeability increases. This topic is evaluated for lower depths below the tunnel (see fig. 10 and 11). Thus, it seems that increasing the soil permeability causes excess pore pressure to decrease due to the liquefaction and the reduction has a main effect on forces of the tunnel lining.

## 6. Conclusions

The paper is designed to assess the effect of drain conditions on variations of pore pressure. For this purpose, the effects of drain conditions have been evaluated for static and dynamic cases. Furthermore, the effect of permeability parameters is assessed as a main

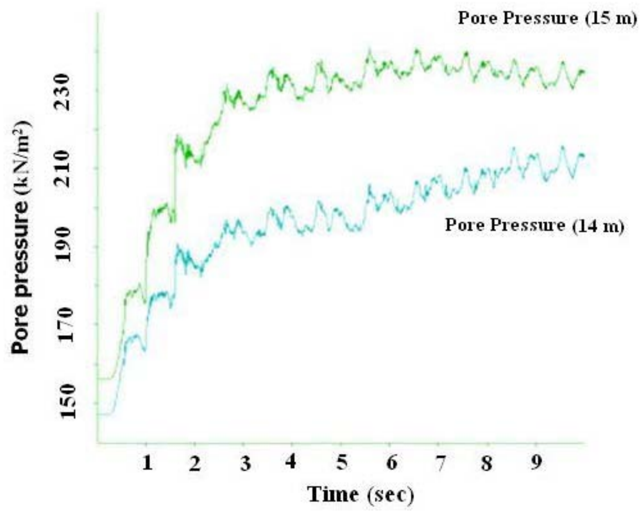


Fig. 10.Variations of pore pressure at the depths of 14 (m) and 15 (m) from ground surface (lower depths of tunnel crown, K= $10^{-4}$ m/s)

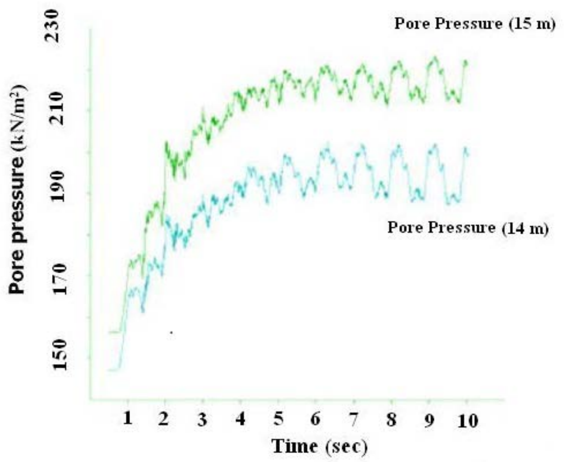


Fig. 11.Variations of pore pressure at the depths of 14 (m) and 15 (m) from ground surface (lower depths of tunnel crown, K= $10^{-3}$ m/s)

parameter of drain conditions and the results are follows:

1. In the static loading, changing the drain conditions from undrained to drained causes the bending moments and axial forces to decrease. Removing the excess pore pressure in a drained condition in comparison with the undrained condition is the reason of reduction. Thus, fewer forces push the tunnel lining, and therefore deformation and interior forces of the tunnel lining decrease.
2. Increasing the friction angle causes the bending moments, axial forces and shear forces of the tunnel lining to increase for both drain conditions under static loading. Furthermore, the average deformation of the tunnel lining in the undrained condition (11 mm) is greater than the drained condition (4 mm). The reduction is about 63%.
3. On the basis of these analyses, structure uplift and surface heave are reduced extremely. Furthermore, forces and bending moments of the tunnel lining under dynamic loading for drained condition decrease about 10% in comparison with the undrained condition.
4. Increasing the soil permeability causes excess pore pressure and as a result, forces of the tunnel lining to decrease. According to these studies, increasing the permeability from $10^{-4}$ (m/sec) to $10^{-3}$ (m/sec) causes the bending moments and shear forces to rise 16.2% and 0.3% respectively. Furthermore, tunnel uplift reduces almost 5%.

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