Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 54(10) (2023) 739-742
DOI: 10.22060/ceej.2022.21082.7611

A numerical study of piezocone test in Firoozkooh sandy soil under different drained conditions

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ABSTRACT: The piezocone penetration test is commonly used to measure pore water pressure, identify soil profiles and estimate their material properties. Depending on the soil type, ranging from clay to sand, undrained, partially drained, or drained conditions may occur during cone penetration. In silt and sand–clay mixtures, the piezocone penetration is characterized by partially drained conditions, which are often neglected in data interpretation. The effect of drainage on piezocone measurements has been mainly studied experimentally. Numerical analyses are rare because taking into account large soil deformations, soil–water and soil–structure interactions, and nonlinear soil behavior are still challenging tasks. In this paper, using an advanced hypoplastic constitutive model and ABAQUS finite element software, large deformations and nonlinear behavior of soil during penetration were modeled, and the behavior of Firoozkooh saturated sandy soil having different drainage conditions and relative densities were analyzed. Then, using the obtained results, the range of influence of cone penetration on the surrounding soil and the range of partial drainage conditions for Firoozkooh sandy soil were investigated. It was also shown that drainage condition and density of the soil had a significant effect on the affected soil area and the trend of changes in excess pore water pressure.

Review History:

Received: Feb. 07, 2022
Revised: Mar. 25, 2022
Accepted: Apr. 13, 2022
Available Online: Apr. 28, 2022

Keywords:

Piezocone Test
Partial Drainage
Numerical Modeling
ABAQUS Software
Hypoplastic constitutive model

1- Introduction

In the current conditions, the CPT penetration test (CPT) due to its high efficiency in providing a continuous profile of soil stratification and acceptable estimates of the geotechnical properties of subsurface layers for clayey and sandy soils, as well as the appropriate test speed and economic characteristics have become a common test worldwide. The results of the cone penetration test can be used to estimate mechanical properties in fine-grained soils and sands. Depending on the type of soil ranging from clay to sand, any of the undrained, partially drained or drained conditions may occur during the cone penetration process, while in most studies on cone penetration test, the soil is considered only as undrained or fully drained, but cone penetration in silty soils is performed under partially drainage conditions, which is often important in interpretation. Very few numerical studies have been performed that can simulate the complex behavior of the Piezocone penetration test. So, a comprehensive numerical study considering the above-mentioned complexities and different drainage conditions seems necessary.

2- Methodology

In this study, the process of cone penetration in sandy soils is simulated using Abaqus software. In order to prevent excessive distortion of soil elements around the piezocone at the beginning of the penetration process, the cone-shaped area of the piezocone is considered to be buried at the top boundary of the mesh. For contact-friction modeling between the cone-rod and the surrounding soil, during the penetration process, a kinematic algorithm is used, which does not allow the penetration of cone elements in the surrounding soil elements. In this study, the behavior of soil grains was modeled using a hypoplastic constitutive model and using Firoozkooh 161 sand, that hypoplastic parameters were obtained based on Mohammadi Haji and Ardakani (2020) laboratory tests. The values of each of the parameters used for this constitutive model are given in Table 1. A schematic of this axisymmetric model is shown in Figure 1.

Table 1. Parameters of Firoozkooh sand hypoplastic constitutive model

Parameters	α	β	e_{d0}	e_{c0}	e_{i0}	φ_c (°)	h_s (MPa)	n
Firoozkooh sand	0.5	1.0	0.58	0.91	1.1	32.7	350	0.24

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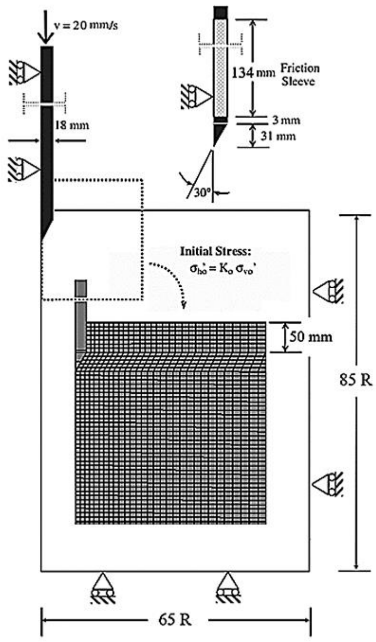

Fig. 1. Boundary conditions and initial meshing of the finite element model

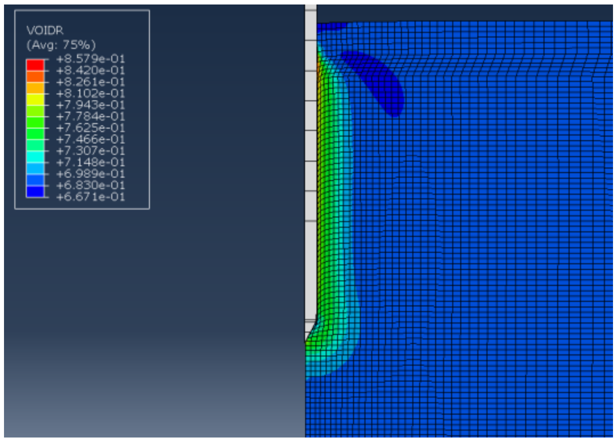

Fig. 2. Changes in void ratio with distance from the tip of the cone at a density of 60%

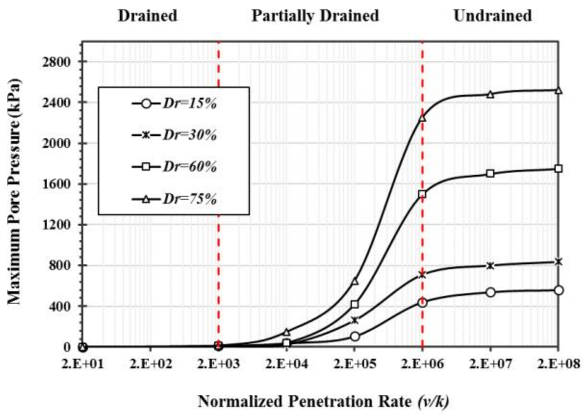

Fig. 3. changes in maximum pore water pressure with normalized penetration rate for different densities of Firoozkooh sand

3- Results and Discussion

In this section, the effect of partial drainage on the cone penetration process is discussed. For this purpose, numerical analyses to simulate cone penetration and pore water pressure dissipation tests have been performed using Abaqus finite element software. In this study, Firoozkooh sandy soil with hypoplastic constitutive model having properties shown in Table 1 was used. For the analyses performed, 4 densities of 15, 30, 60 and 75% and permeabilities of 10^{-3}, 10^{-5}, 10^{-7} and 10^{-8} m / s have been considered. Figure 2 shows the changes in the void ratio of soil with cone penetration for a sample with a density of 60% and a permeability of 10^{-5} m/s. According to this figure, it can be seen that with the penetration of the cone, the soil void ratio in an area of about 3 times the radius of the cone has been affected.In the following, the process of changes in the excess pore water pressure at the tip of the cone over time for the different densities has been investigated by performing dissipation tests. It is observed that the trend of changes in the pore water pressure is different for different values of densities and permeabilities. For the cases of soil having high densities (60 & 75%), the negative excess pore water pressure at high permeabilities (10^{-3}m/s), reached a positive value over time and then depreciated, but at low values of permeabilities (10^{-8} m/s) the excess pore water pressure, which was initially negative, is dissipated without changing the sign. The reason for this observation that there is the different mechanism by that the cone penetrates into the soil with different densities.In this study, by examining different drainage conditions, a gradual change in the behavior of characteristics such as excess pore water and void ratio around the cone, passing from undrained to fully drained, was observed. Therefore, identifying the area for soil permeability as the area of soil permeability with partial drainage is important and makes it possible to know more about the characteristics of the soil. For this purpose, for Firoozkooh sandy soil, analysis was performed for different permeabilities, the results of which are shown in Figure 3. In fact, not only soil permeability is effective in determining the soil drainage range, but also the cone penetration rate is effective in determining soil drainage conditions. As can be seen in this figure, the soil in the normalized penetration rate range of 2e3 to 2e6 shows a partially drained behavior and has an increasing trend, and in the normalized penetration rate range less than 2e3 the soil behavior is drained. Also, in the range of values greater than 2e6, the soil behavior can be considered as undrained and with increasing normalized penetration rate in this range, the amount of pore water pressure remains almost constant.

4- Conclusions

The main purpose of this study was to investigate the changes in excess pore water pressure, in drainage conditions and the different densities. The following results can be summarized as follows:

1. Changes in the soil void ratio around the cone in the radial direction were investigated and it was observed that with decreasing soil permeability, the radial range of the void ratio decreases.

2. Gradual changes in the behavior of characteristics such as excess pore water and void ratio were observed by passing from the undrained to the drained state around the cone.

3. Increasing the amount of pore water pressure created by increasing the soil density, so that for example, by increasing the percentage of soil density from 60% to 75%, the maximum amount of pore water pressure increases by about 44%.

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HOW TO CITE THIS ARTICLE

M. J. Mashinchian, M. M. Ahmadi, A numerical study of piezocone test in Firoozkooh sandy soil under different drained conditions, Amirkabir J. Civil Eng., 54(10) (2023) 739-742.

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