Chapter 12

Consideration of Pumice Sand-Concrete Interface Friction in Pile Modeling

İbrahim Yiğit[1]

Abstract

In geotechnical engineering designs, it is necessary to know the friction mechanism on the soil-structure contact surface as well as the mechanical properties of the soil. Geotechnical structures, such as friction piles derive their reaction force entirely from this mechanism. For this reason, there are many studies in the literature examining the soil interface friction with building materials such as wood, steel and concrete, on which geotechnical structures can be built. However, there is a deficiency in the literature on examining the interface friction of pumice sand and building materials. Nevetheless, there are settlements built on pumice soil sections and this behavior should be known in the design of geotechnical structures in these regions. The most characteristic feature of pumice soil grains is that they have a very large internal void ratio and therefore they can be easily crushed under external loads. In terms of these properties, they can be expected to exhibit a different mechanical behavior than other granular soils. The most important factors affecting the interface friction of granular soils and building materials are stress level, soil fabric, soil particle size distribution, shape-texture of soil grains and surface roughness of the building material. The most widely used test in the laboratory for the investigation of soil and building materials interface friction has taken its place in the literature as the direct shear box test. The advantage of this test is that both the internal friction angle of the soil and the interface friction angle of the soil with the building material can be obtained under similar boundary conditions. Thus, the strength parameters of the material are obtained. Definitely, more comprehensive tests such as triaxial tests are needed to obtain elastic material parameters. By using all these material parameters, stress strain analysis of geotechnical structures can be performed with numerical methods such as the finite element method. In this context, the stress strain analysis of a single pile was investigated by the finite element method, strength parameters and the pumice sand concrete interface friction angle, which were obtained in the laboratory of the loosely prepared pumice sand.

1 Dr., Isparta University of Applied Sciences, ibrahimyigit@isparta.edu.tr,
Orcid: 0000-0001-5485-9222

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1. Introduction

In the design of geotechnical structures, it is necessary to know the interface friction angle between the soil and the construction material. There are many studies on the determination of the interface friction angle between the construction materials and soils. The main studies can be listed as; Potyondy (1961), Uesugi and Kishida (1986), Uesugi et al. (1990), and Jardine et al. (1993).

Potyondy (1961) presented a very comprehensive study examining the interface friction of dry and saturated sand with wood, concrete and steel materials. Tests were carried out in a direct shear box with a square section of 60x60 mm. Author stated that the interface friction angle (δ') varies depending on the water content, the particle size distribution, the density of the soil, the stress level, and the surface roughness of the construction material used. Author concluded that on very rough surfaces, the interface peak friction angle (δ'_{pik}), approaches the peak value of the internal friction angle of the soil (ϕ'_{pik}), but in all cases it is obtained as $\delta'<\phi'$.

Uesugi and Kisihida (1986) studied a range of dry sand and steel interface frictions with simple shear test. Authors stated that the type of sand used and the steel surface roughness were very effective on the interface friction, whereas the normal stress and mean grain size had less effect. Authors also concluded that if the steel surface is smooth enough, sliding occurs at the steel-sand interface, but if the steel surface is sufficiently rough, shear failure occurs in the sand mass.

Uesugi et al. (1990) investigated the sand-concrete interface friction under cyclic loading with a simple shear test. They noted that under monotonic loading, tangential displacement mostly occurs in the sand mass at the yielding condition. They emphasized that the tangential displacement after yielding is mostly due to interface sliding. They stated that a shear band is formed at the sand-concrete interface and the shear stress ratio occurring in this shear band is smaller than that of the dense sand sample. However, they concluded that the friction at the sand-concrete interface is characteristically similar to that at the rough steel-sand interface.

Jardine et al. (1993) performed a series of direct shear interface tests in which they examined the interface friction of steel and various cohesionless soils. In the experiments, the effects of relative density, mean grain size and stress level on shear resistance were investigated. 10° higher internal friction angle was obtained in dense sand samples than loose samples, and that the initial void ratio and relative density of the sand had a significant effect on the peak internal friction angle. In all cases, the internal friction angle tends to a similar critical state value of 33° after the dilation stops and the shear stresses are balanced. Interface friction tests on the smooth steel and smoother teflon materials, gave similar trends with the internal friction tests on sand. Authors concluded that for each particular interface, the initial relative density affects the amount of expansion and δ'_{pik}, but not the critical state interface friction angle (δ'_{CS}). The δ'_{CS} decreases inversely with D_{50} and has the upper limit of the critical state internal friction angle (ϕ'_{CS}). The sand samples tend to compress after yielding when the relative density is less than 60% and to expand when it is greater than 70%. When the relative stiffness is greater than 70%, mobilized δ'_{pik} angles exceeding δ'_{CS} with a margin increasing with relative density.

In this study, the internal friction angle of the pumice sand and the interface friction angle between the pumice sand and the concrete were investigated by direct shear box test in the laboratory. By using the test data obtained for these materials, the stress strain analysis of the direct shear box test was carried out using the finite element method. Thus, the test calibration was done. Following this, the axial loading of the single pile in the pumice soil was carried out again using the finite element method.

2. Materials and Methods

In this section, stress strain analysis of the friction pile in pumice soil using the finite element method will be discussed. However, firstly, the pumice soil internal friction angle and pumice soil concrete interface friction angle obtained by direct shear box test in the laboratory will be explained. In addition, the same shear box test will be numerically modeled with the finite element method and parameter calibration will be performed.

2.1. Obtaining Pumice Sand Internal Friction Angle and Pumice Sand Concrete Interface Friction Angle by Direct Shear Box Test

As mentioned before, the gradation curve has a significant effect on the internal friction angle and the interface friction angle. The gradation curve of the pumice sand used in this study is given in Figure 1. The pumice sand has a well-graded structure. In addition, the chemical properties of the pumice sand are given in Table 1.

The concrete slab manufactured to be used in this study is given in Figure 2.a. The 28-day compressive strength of concrete was obtained as 25 MPa from the results of the one-dimensional loading test performed on the cube specimens produced from the same concrete mixture. The concrete slab, which has a very rough surface, placed in the lower cell of the shear box is given in Figure 2.b. The top cell of the shear box is added to this is given in Figure 2.c. The pumice sand placed in the upper cell of the shear box is given in Figure 2.d. Shear box tests were carried out according to ASTM D3080 standard. Internal and interface friction tests were conducted under 100, 200 and 400 kPa normal stresses. The results of internal friction and interface friction tests were given in Figure 3.a and b. Using this test results internal friction and interface friction angle was found 36° and 33° respectively.

Table 1 Chemical properties of pumice sand (Çimen et al. 2020)

Content	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	K_2O	CaO	TiO_2	MnO	Fe_2O_3
%	5.3	1.1	17.1	60.9	0.2	5.0	3.0	0.3	0.1	3.2

2.2. Finite Element Modeling of Direct Shear Box Test

Shear box tests were modeled using the finite element method, similar to Hegde and Roy (2018). In the analysis, the hardening soil model for pumice sand and the Mohr Coulomb model for concrete were used. The material parameters used in the analyzes for both materials are given in Table 2 and the analysis results are given in Figure 4. The geometric models, loading state and boundary conditions are given in Figure 4.a-1 for the pumice sand internal friction angle test and in Figure 4.b-1 for the pumice sand concrete interfacial friction angle test. Although the boundary conditions and loading conditions are the same in both experimental models, the materials in the base geometry in the first and second experiments are pumice sand and concrete, respectively. However, the interface element is defined between materials in the interface friction angle test model. Horizontal displacement values for both experimental models are given in Figure 4.2 and 3 as shading and vectors. Finally, the relative shear stresses were obtained as given in Figure 5.3.

Figure 1 Gradation curve of pumice sand

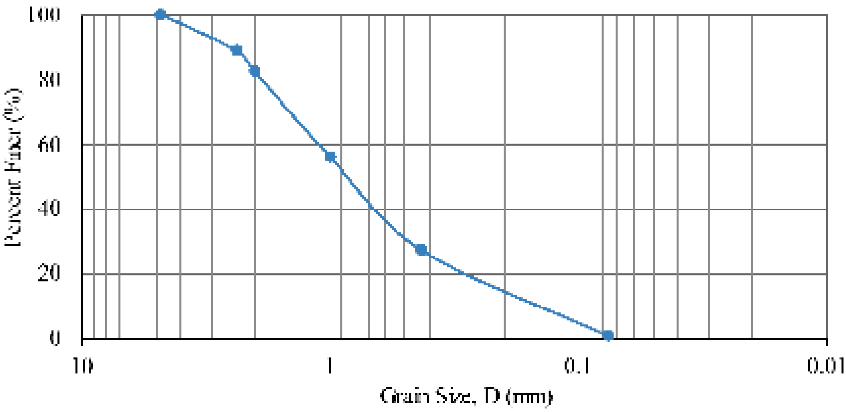
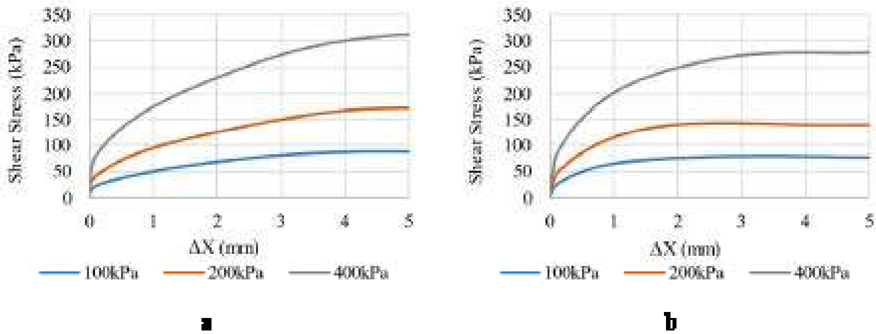


Figure 2 a) Concrete plate, b) Concrete plate in base cell, c) Concrete plate in base cell and top cell, d) Top cell filled with pumice sand

Figure 3 a) Direct shear internal friction angle test results of pumice sand, b) Direct shear interface friction angle test results of pumice sand and concrete



2.3. Modeling of Friction Pile in Pumice Sand

The material parameters of pile and pumice sand are given in Table 2. The geometric model was chosen as axisymmetric and the pile diameter was used as 1m. The pile is modeled as a linear elastic material. Groundwater is not considered. In the model, an interface element is used between the soil and the pile. A reduction in the internal friction angle, which is the soil shear strength parameter, is applied on the interface element and the pile-soil contact surface. From the previously mentioned shear box tests, the pumice soil internal friction angle $\phi = 36°$ and the pumice sand-concrete interface friction angle $\delta = 33°$. For the pumice sand, the interface reduction factor is $R = \tan\delta / \tan\phi \approx 0.9$. However, this value is generally used in the literature for sands in the range of 0.8 - 1.0. Therefore, analyzes were performed for the 0.8 and 0.9 values of the R reduction factor. The vertical displacement values of the pile are given in Figure 5.b and c. Pile loading values and corresponding maximum vertical displacement values are obtained as given in Figure 6. The interpretation of these graphs will be discussed in the results and conclusions section.

Table 2 Model parameters

Parameter	Pumice Sand	Concrete	Pile
Model Type	Hardening	Mohr Coulomb	Linear Elastic
E (kN/m^2)	10^4	30x10^6	30x10^6
m	0.8	NA	NA
v	0.3	0.2	0.2
ϕ ∘	30	35	NA
c (kN/m^2)	1	365	NA
ψ ∘	1	0	NA
γ (kN/m^3)	16	25	25
R	0.8 – 0.9	1	1

Figure 4 1) Geometry, materials, loads and boundary conditions, 2) Horizontal displacements (shading), 3) Horizontal displacements (vectors), 4) Relative shear stresses

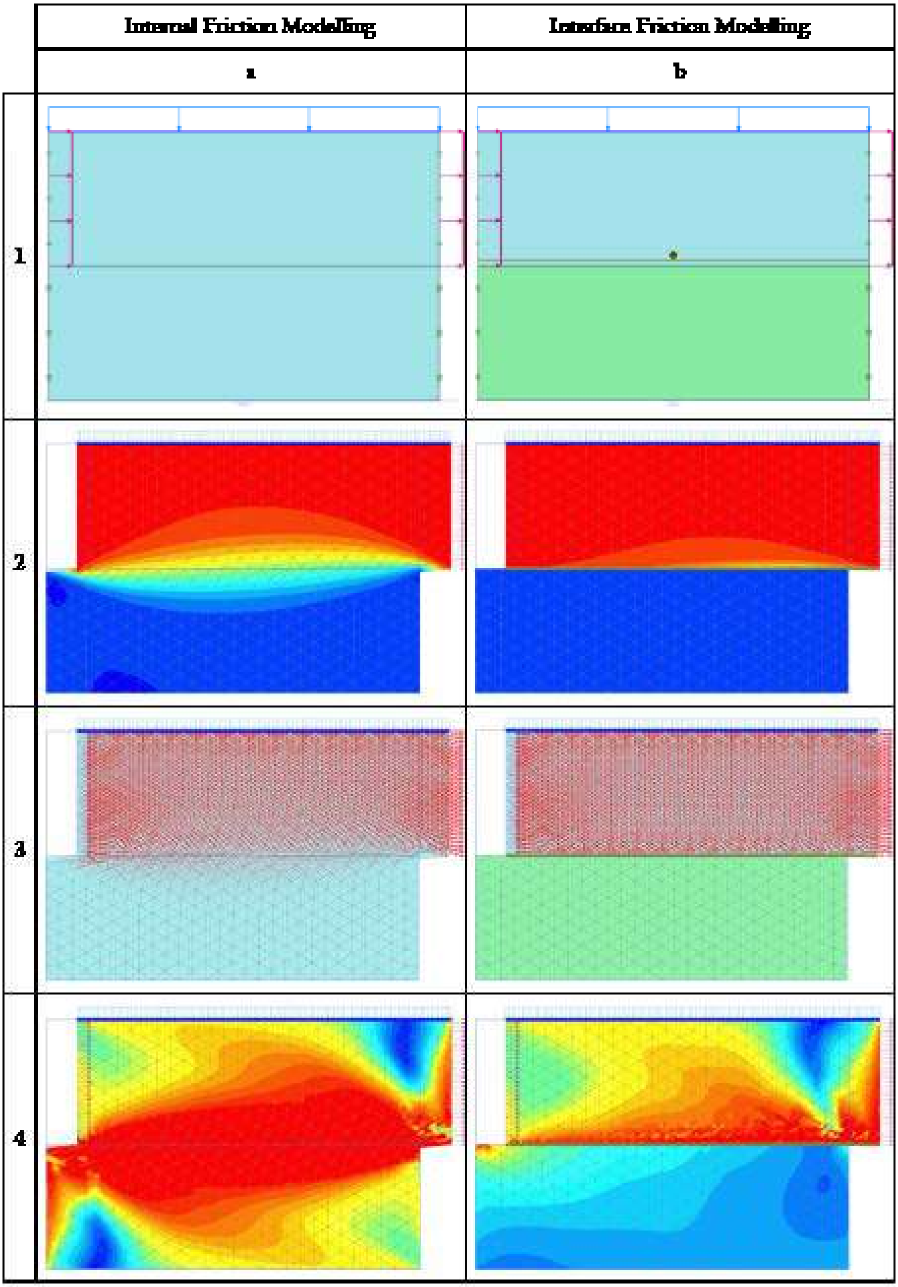


Figure 5 a) Geometry and mesh b) Vertical displacement (R=0.9) c) Vertical displacement (R=0.8)

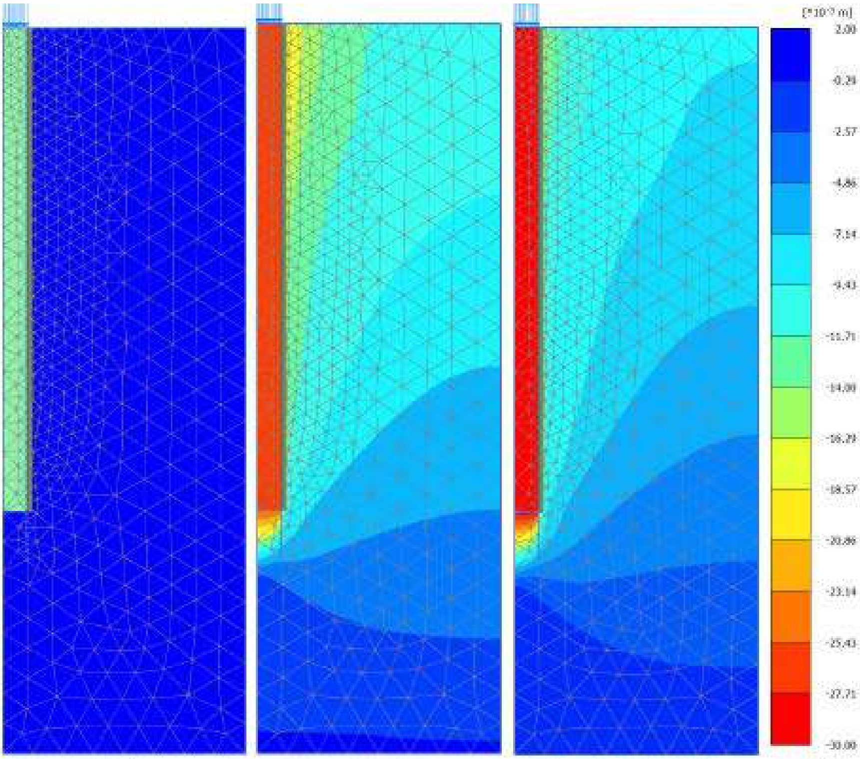
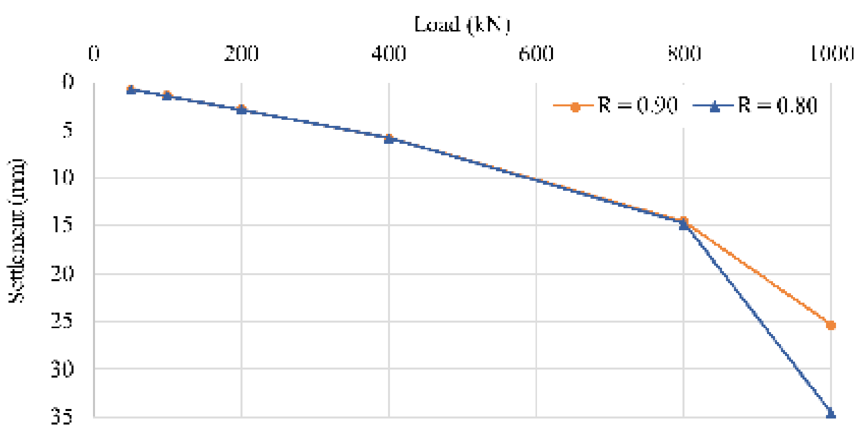


Figure 6 Pile load – vertical displacement curve.



3. Results and Conclusions

Interface friction of concrete with pumice sand was investigated. Both pumice sand internal friction angle and pumice sand concrete interface friction angle were obtained in 60x60 mm square section direct shear box tests. With the obtained test data, a direct shear box finite element model was created and parameter calibration was done. In the internal friction angle test model, horizontal displacements occur in both the upper and lower parts (Figure 4.2.a), while in the interface friction angle test model, horizontal displacements are only seen in the upper part (Figure 4.2.a). A similar situation is also valid for the relative shear stresses given in Figure 4.4.a-b.

Using the parameters obtained from the shear box laboratory tests and finite element modelling, a pile model was created in the pumice sand. The geometry, loading condition, boundary conditions and finite element mesh of the created model are given in Figure 5.a. Analyzes were made by taking the strength reduction coefficients of 0.9 and 0.8 in the interface element used between the soil and the pile in the model. The maximum vertical displacement values of the pile are given in Figure 5.b and c for R = 0.9 and 0.8, respectively. R coefficient controls the shear strength in pile-soil interface. The load values used in the pile model and the corresponding vertical displacement values are shown in Figure 6. While both curves were approximately coincident until the load value of 800 kN, a large deviation was observed after this value. Following conclusion can be drawn from here; At the pile-soil interface, yielding occurred at this loading level, plastic deformations developed faster and settlement values were higher in the case of R = 0.8 than in the case of R = 0.9. This result is consistent with the result presented by Uesugi et al. (1990).

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