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Flow velocity during radial consolidation of Sungun copper mine slurry tailings under vacuum preloading

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Abstract

Evaluation of flow velocity in a porous medium is one of the important subjects in geotechnical engineering. Mine tailings with high water content larger than the liquid limit in the form of slurry have high compressibility, hence, a suitable improvement method such as vacuum preloading is required to use materials in the tailings dam. The present study investigates the effect of sample water content and suction pressure level on time-dependent changes in flow velocity. The tests are performed on saturated samples of fine-grained tailings from the Sungun copper mine. The results show that the graphs of drained water volume and vertical strain of samples follow an exponential function of time with a very good approximation. Assuming Darcian flow through the test materials, relationships are presented to determine the flow velocity based on two approaches including the pore water discharge rate and vertical strain rate of samples. Then, results of the two approaches in calculating the flow velocity and interpreting laboratory observations are compared. The results also demonstrate that the flow velocity increases with sample water content and suction pressure. In addition, vacuum preloading continues until samples reach a certain void ratio. Furthermore, a new relation is proposed to calculate the average degree of consolidation for the layer based on the flow velocity ratio. Finally, the proposed relationship is accurately verified with the estimation of the volumetric compressibility coefficient for the data of the present study using the Oedometer test and a vacuum preloading improvement project on Dalian coast of China

Keywords: *Flow velocity, Strain rate, Suction pressure, Water content, Vacuum preloading*

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Extended Abstract:

1. Introduction

The establishment of suction produces a hydraulic gradient and a consequent flow through a porous medium (Li et al., 2018). Besides, the rate of excess pore pressure dissipation and the change of sample volume under loading are related to the flow rate. One of the important aims of the flow study is the investigation into the consolidation due to pore water drainage during preloading. Since vacuum preloading assisted by vertical drainage is a type of radial consolidation, measuring the flow velocity under radial drainage is useful for controlling the consolidation degree of slurries. However, none of the past studies have specifically determined the velocity of pore water flow through the soil under vacuum preloading.

In the current research, the velocity of pore water flow in slurried materials with very high water content is measured during the vacuum preloading tests. Then, new relationships to calculate the flow rate based on two approaches of using the discharge rate and strain rate are presented, and the results are compared with each other.

The slurries studied in this research are related to the tailing materials of Sungun copper mine, which are stored in the tailing dam reservoir, and the main feasibility goal is to use the vacuum preloading improvement technique to accelerate the consolidation settlement of copper slurry tailings. Imposing the occurrence of long-term settlements in a short time makes it possible to store a larger amount of tailings in the dam reservoir in a certain period of time, which will optimize the use of the capacity of the tailings dam.

2. Materials and methods

Sungun copper mine is an open pit mine in the northwestern region of Iran (43° 46´ E and 38° 42´ N) and is located near Aras River, 120 km from Tabriz. Metal minerals are widely present in the geological formations of Aras watershed in Iran. Sungun copper mine is very important in terms of industry and geological features in the mentioned region. This mine has reserves of approximately 800 million tons of copper ore with an average grade of 0.67%, in such a way that the production of at least 380 million tons of copper waste is estimated in the next 25 years. Geologically, the studied area is located in the Oligocene volcanic zone. This area includes calc-alkaline volcanic rocks, mainly trachy-andesite, dacite, and andesite with basaltic lava. Songun porphyry copper deposits are found in trachyandesite rocks that contain pale gray porphyry latite with medium to severe weathering and medium to high resistance. The color of the areas affected by the penetration of underground water changes to brown and with increasing depth, traces of sulphide minerals (including pyrite and chalcopyrite) are found in the materials. Andesite is among fine-grained volcanic rocks. Dacite has a fine-grained (aphanitic) to porphyry texture and is intermediate between andesite and rhyolite in terms of composition (Fig. 1). The average size of andesite and dacite grains ranges from 27 to 83 microns.

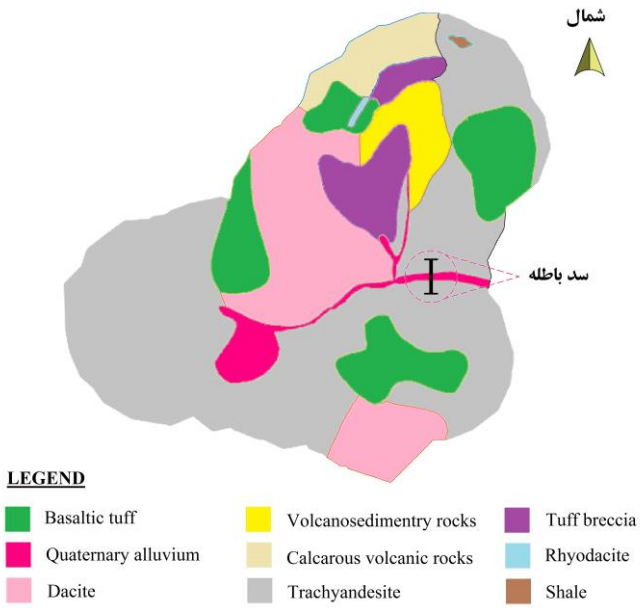

Fig. 1. Simplified petrology map of Sungun copper mine

To attain the research goals, a vacuum consolidation laboratory device has been designed as illustrated in Fig. 2. The test setup consists of six main parts, including a material tank, vacuum pump, vacuum chamber, vacuum pressure gauge, vertical drain, regulating valves (suction, discharge, and drainage valves), tank lid, and connecting hoses along with other side parts. Under vacuum preloading, changes in pore water pressure can be calculated according to the radial distance of any point from the centerline of the vertical drain using Eq. (1):

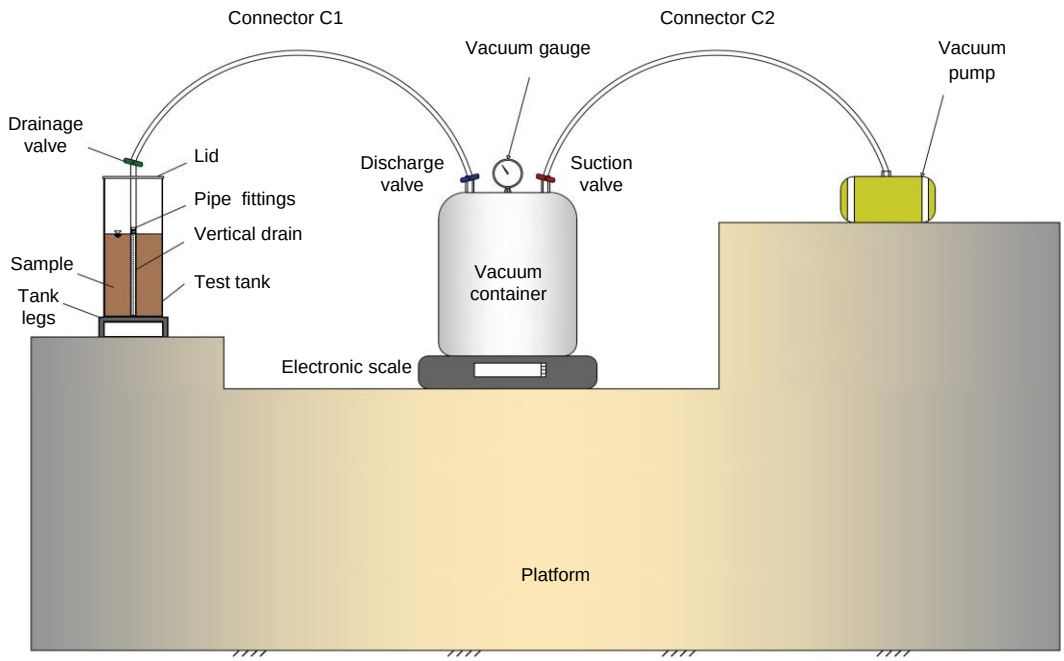

Fig. 2. Schematic setup configured for vacuum preloading tests

The rate of excess pore water pressure dissipation in radial direction: $$\frac{\partial u}{\partial r}=\frac{\gamma_w}{2k_h}\frac{\partial \varepsilon}{\partial t}\left(\frac{R^2-r^2}{r}\right) \quad (1)$$

3. Tests results

Many results are obtained through the current experiments, concerning volume changes in terms of sample water content and duration of vacuum preloading. One of the most important yet innovative findings of the present study is the calculation of the flow velocity ratio ($n_{vel} = \overline{v}_{app1}/\overline{v}_{app2}$) at any time of tests. Variations of n_{vel} against the initial water content of each sample are shown in Fig. 3.

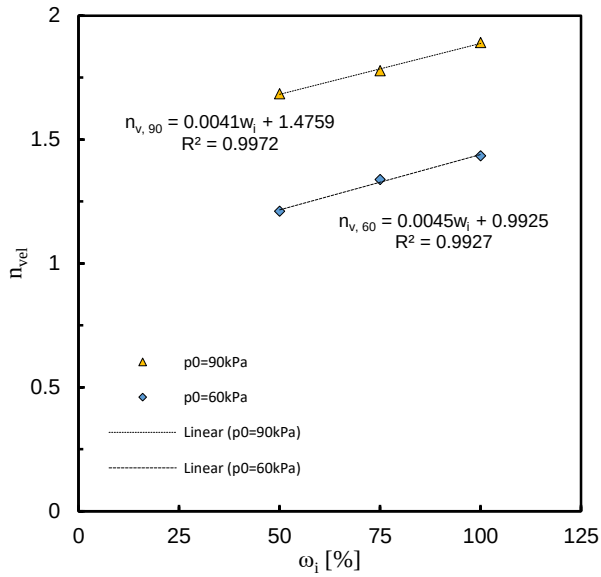

Fig. 3. Variation of n_{vel} with initial water content of samples

From Fig. 3, it can be concluded that at a constant vacuum pressure, the flow velocity ratio increases with the sample water content. Furthermore, for constant water content, the larger the applied suction pressure, the larger the n_{vel}. Investigations also indicate that the flow velocities due to the two approaches are equal to each other when the value of the equivalent radius is considered to be approximately equal to $r_{eq} = n_{vel}r_w$.

4. Conclusion

In this experimental and analytical study, the impact of suction intensity balance and initial water content on pore water discharge rate and vertical strain due to the vacuum preloading method for saturated samples of fine-grained tailings related to the Sungun copper mine was evaluated. Based on results, the most significant conclusions can be drawn as follows:

At the initial moments of suction application, the flow velocity values obtained from the two approaches are almost equal to each other, but the flow based on the first approach gradually becomes faster than in the case of using the second approach. Unlike the second approach, the first approach only determines the flow rate based on the volume change process of the sample caused by the discharged volume of water and does not take into account the effects of the radial consolidation parameters and the rate of excess pore water pressure dissipation. Hence, $\overline{v}_{app1}$ is

larger than $\overline{v}_{app2}$, and it can be concluded that the second approach provides more realistic results for the flow velocity under vacuum preloading.

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