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UPWARD-SEEPAGE EFFECTS ON BOTH EXCESS PORE-WATER PRESSURE AND SHALLOW-FOUNDATION STABILITY ABOVE SATURATED SAND

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ABSTRACT: Upward seepage of water is indicated by the presence of Excess Pore Water Pressure (EPWP), and liquefaction occurs. In this paper, the effects of upward seepage are discussed based on observations of the physical model in the laboratory. The samples of sand are collected from two areas in Padang City, Indonesia. The gradation (sieve analysis) tests are then carried out to obtain sand fraction based on the United Soil Classification System (USCS). The present experimental results show that upward seepage in saturated fine-sand causes an increase in the EPWP so that the effective stress decreases. Consequently, the shallow foundation above it becomes unstable. While the addition of coarse sand on saturated sand can reduce the EPWP so that the effective stress increases and the shallow foundation becomes stable.

Keywords: Upward Seepage, EPWP, Liquefaction, Shallow Foundation, Saturated Sand

1. INTRODUCTION

Seepage can either increase or decrease the effective stress at any point in a mass of the soil. Upward seepage can increase the excess pore-water pressure, EPWP [1]. The resulting EPWP under undrained load condition is a characteristic of all liquefaction phenomena. When non-cohesive soils are saturated, then suddenly, there is a rapid loading under undrained conditions, then the grains tend to densification, which causes EPWP to increase and effective stress decrease [2]. The increase in pore water pressure is due to the tendency of the grained material to densify when experiencing cyclic shear-loads [3].

The settlement of a building with shallow foundations is due to the lack of both stiffness and bearing capacity of the soil under the building. Large deformation of soil can occur when the soil under the structure liquefies and loses strength so that the structure to settle and tilts [4].

Based on the previous researches, there are three variables that cause the reduction of non-cohesive soil strength, namely the fines content, relative soil density, and hydraulic gradient in the soil sample. Soils with fine and coarse fractions are susceptible to an increase in the permeability coefficient, which is in turn to decrease the soil strength [5].

The West Sumatra earthquake of 30 September 2009 caused liquefaction in Padang city and nearby areas. The resulting liquefaction caused ground settlement and sand boiling. Many buildings that close to the river banks experienced foundation movements due to this ground settlement [6,7].

Yuliet *et al*. investigated the liquefaction potential at the Nurul Haq Shelter area (near Muaro Baru) in Padang City, Indonesia. The results showed that the location has a high potential of liquefaction [8]. The results also showed that sand deposition at a certain depth around Pasir Jambak (near also Muaro Baru) has the liquefaction potential [9].

For this reason, sand near the beach and river banks in Padang city, especially Muaro Baru, needs to be investigated further about the effects of upward seepage on both EPWP and the stability of shallow foundations above saturated sand. The objectives of the present study are to observe the stability of shallow foundation above saturated sand with variations of sand fraction; To find the relationship between EPWP and the depth of fine sand and coarse sand above medium sand.

2. STRESS IN SATURATED SANDY SOIL DURING UPWARD SEEPAGE

The effective stress at each point in the soil mass can vary due to water seepage through it. This effective stress can be either increase or decrease depending on the direction of seepage. Seepage is defined as the process of water flowing in the pores of the soil. Upward seepage increase pore-water pressure (u), where pore-water pressure is equal to EPWP plus hydrostatic pressure ($\gamma_w.z$). The contact force among the sand grains is called the effective stress (σ'), which is equal to total stress (σ) subtracted by pore water pressure (u).

When the pore water pressure increases, the effective stress at each point in the soil mass decrease. If the rate of seepage increases slowly up to reach in where the effective stress equal to zero, the sand behaves as a liquid. This situation is called a boiling condition. In this condition, the soil stability is lost and the soil is deformed largely. Dissipation of high EPWP results in soil subsidence (Settlement) [10].

The sand boiling phenomenon is closely related to liquefaction. Sand boiling is diagnostic evidence that pore pressure has increased and indicates that liquefaction has occurred [4,11].

3. EPWP TEST BY UPWARD SEEPAGE FLOW

3.1 Test Apparatus and Materials

In the present study, a square tank with upward seepage is used to measure EPWP. The tank is made of transparent acrylic material with a thickness of 1 cm. The width of the inner tank is 15 cm and the length of the inner is 100 cm (Fig. 1).

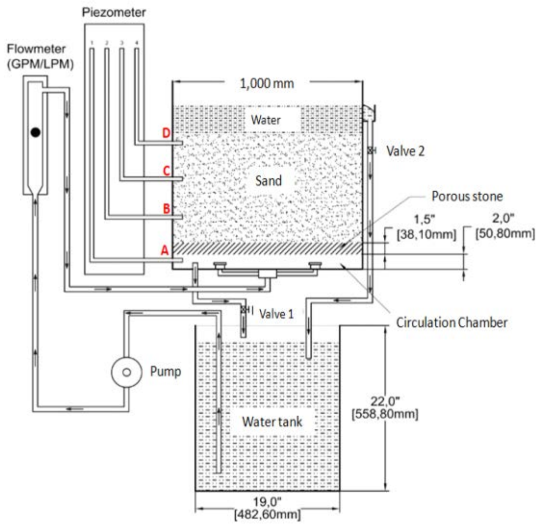

Fig.1 Model of EPWP made of acrylic

Piezometer tubes made of acrylic are installed at 4 points, namely point A, point B, point C and point D at different depths. The piezometer tube is used to measure the head of water during the test. A flow meter with two scales, Gallon Per Minute (GPM) and Liter Per Minute (LPM), is used to determine the rate of flow of water through the soil in a one-time unit (q). In the present test, the value of q is 26 LPM. The foundation size is 15 cm x 15 cm with a weight of 3,420 kg, and it is put on the top surface of the sample.

The sample of the fine sand was collected in Muara Baru, Padang City. It is in the beach close to the river mouth (Fig. 2). For medium sand and coarse sand were collected in Kuranji river in Gurun Laweh Nanggalo. It is about 5 km from the shoreline (Fig. 3). Disturbed soil samples are disturbed soil samples collected at a depth of 30 cm from the soil surface.

Fig.2 Sampling place in Muaro Baru (Padang city)

Fig.3 Sampling place in Gurun Laweh Nanggalo (Padang city)

The sieve analysis tests are carried out for all soil samples. All symbols and names are determined using the United Soil Classification System (USCS), as shown in Table 1.

Table 1 Soil fraction according to USCS

Soil Fraction	Size range
Coarse Sand (CS)	No. 4 (4.75 mm) to No. 10 (2 mm)
Medium Sand (MS)	No. 10 (2 mm) to No. 40(0.425 mm)
Fine Sand (FS)	No. 40 (0.425 mm) to No. 200 (0.075 mm)

Based on Table 1, the present samples consist of coarse sand (CS) collected from Batang Kuranji River in Gurun Laweh (GLN) and shown in Fig. 4, medium sand (MS) collected from the Batang Kuranji River in Gurun Laweh (GLN) and shown in Fig. 5, and fine sand (FS) collected from the Muara Baru (MB) and shown in Fig. 6.

Fig.4 Coarse sand fraction (GLN)

Fig.5 Medium sand fraction (GLN)

Fig.6 Fine sand fraction (MB)

3.2 Experimental Procedures

The next step is to fill the acrylic tank with water up to a certain height. After the water levels in the tank and the piezometer are the same, sand is then put into the tank up to the desired height. Furthermore, the dry and saturated unit weights were measured for each sample. In the present study, there are two scenario models; they are FS scenario and CS-MS scenario. In the first scenario model (FS Scenario), fine sand (FS) is put into the tank with a depth of 37 cm. The water level is made as high as 1.5 cm above the surface of the fine sand. It can be done by taking the water from the tank. It results in the water level is 38.7 cm from the bottom of the tank. Before the upward seepage occurs, it was observed that the initial water level (IWL) on piezometers A, B and C are 38.7 cm, whereas the IWL on the piezometer D is 0 cm because the point D is above 38.7 cm (Fig. 7).

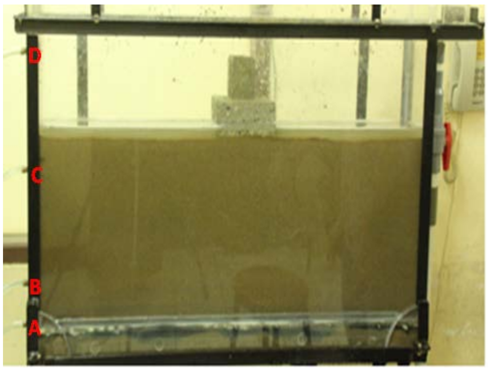

Fig.7 First scenario model (FS scenario)

In the second scenario model (CS-MS Scenario), medium sand (MS) is put into the tank, until 29 cm depth. Then, coarse sand (CS) is put above the medium sand as high as 10 cm. The water level is set around 2 cm above the surface of the coarse sand, so the water level is 41 cm from the bottom of the tank. Before the upward seepage occurs, the initial water level (IWL) on piezometers A, B and C are 41 cm, while on the piezometer D is 0 cm because the point D is above 39 cm (Fig. 8).

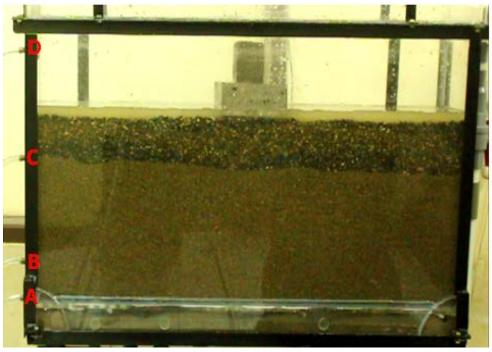

Fig.8 Second scenario model (CS-MS Scenario)

4. RESULTS AND DISCUSSIONS

Fig 9 shows a curve of the particle size distribution of the samples collected from Muara Baru and Gurun Laweh. Table 2 shows the soil classification of the samples.

From Fig. 9, it can be seen that the soil grains passing the sieve No. 200, passing the sieve No. 4, the soil diameter corresponding to 10% finer (D_{10}), 30% finer (D_{30}) and 60% finer (D_{60}). These soil grains also can be seen in Table 2. The soil classification according to USCS shows that the samples from Muaro Baru and Gurun Laweh are poorly graded sand with the group symbol of SP.

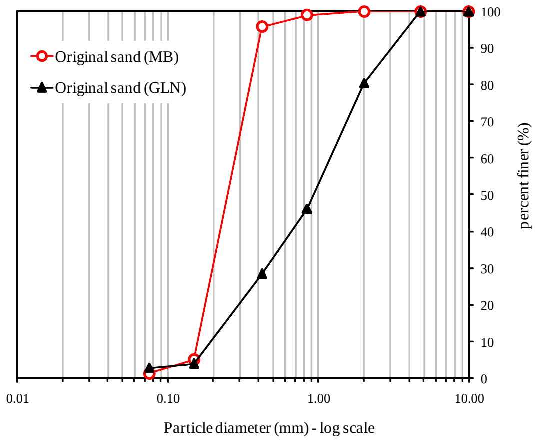

Fig.9 Curve of the particle size distribution

Table 2 Soil classifications of the samples based on USCS

Parameters	Muaro Baru (MB)	Gurun Laweh Nanggalo (GLN)
% passing No. 200 sieve	1.4	2.9
% retained on No. 4 sieve	0	0
D_{10} (mm)	0.16	0.18
D_{30} (mm)	0.19	0.44
D_{60} (mm)	0.27	1.3
C_u	1.7	7.2
C_c	0.84	0.82
Group symbol	SP	SP

Note: SP = Poorly Graded Sand

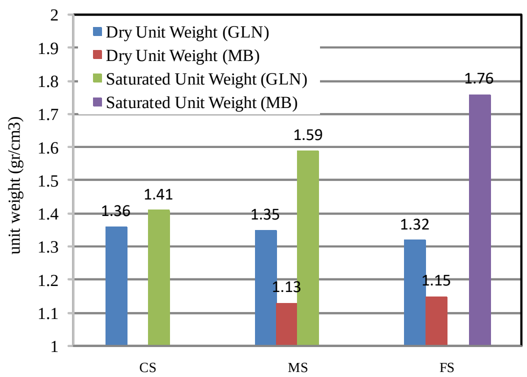

Fig.10 The unit weight of the samples collected from Muaro Baru and Gurun Laweh Nanggalo.

Fig. 10 shows the values of unit weight on sand fractions collected from both sampling places. From Fig. 10, it is seen that the sand fractions have no effect against the dry unit weight. The dry unit weight of the sample from the beach is lighter than that from the river. However, the saturated unit weight of the sample from the beach is heavier than that from the river.

Figs. 11 and 12 show the foundation stability due to upward seepage. The foundation which is put above fine sand becoming unstable (Fig. 11), whereas the foundation which is put above coarse sand remains stable (Fig. 12).

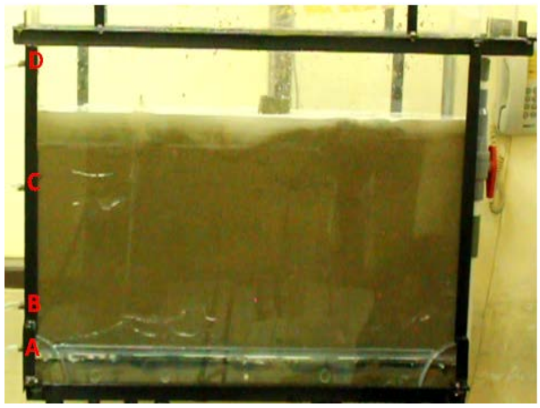

Fig.11 Result of the first scenario model (FS)

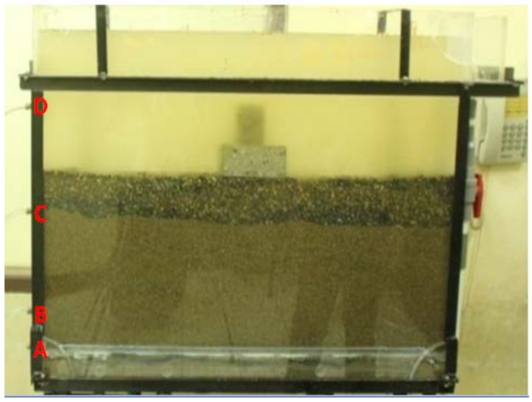

Fig.12 Result of the second scenario model (CS-MS)

Figs. 13 and 14 show the relationship between time and pressure head at levels A, B, C and D. Fig. 13 shows that the pressure head increases at the piezometers A, B and C due to upward seepage. The pressure head of the piezometer D is the same as the water level in the tank, which is as high as 67 cm, which is called the final water level (FWL).

Fig. 14 shows the pressure heads in the piezometers A, B and C increase. The pressure head the piezometer C is the same as the water level in the tank, which is as high as 67 cm (FWL). While the pressure head in the piezometer D is below the IWL and the foundation is in a stable condition (Fig. 14).

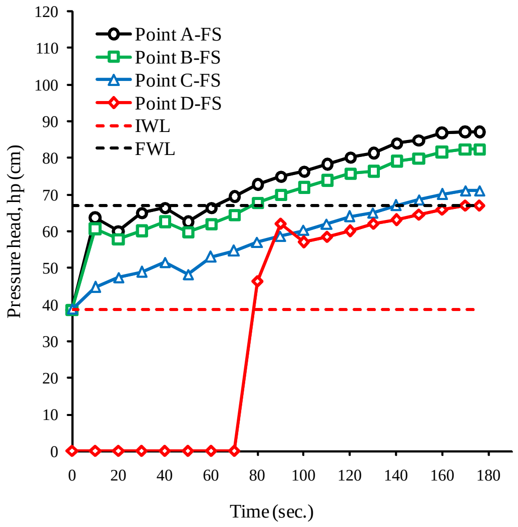

Fig.13 The relationship between time and pressure head for saturated fine sand.

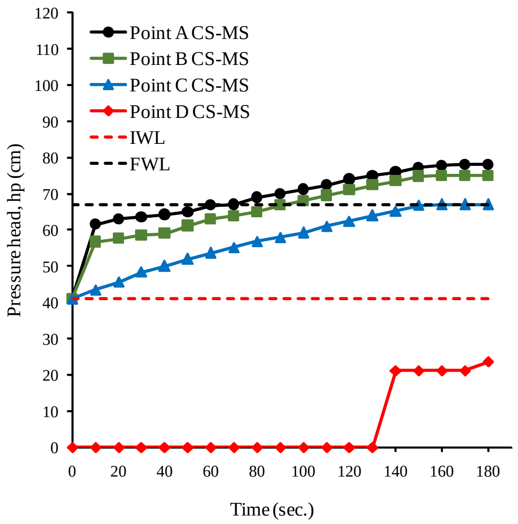

Fig.14 The relationship between time and pressure head for coarse sand above medium sand.

The relationship between depth and EPWP can be seen in Fig. 15. From this figure, it can be seen that the EPWP increases in fine sand (FS) at any depth due to upward seepage. This results in pore-water pressure (u) increasing and effective stress decreasing. As a result, the strength of the fine sand dissipates. Consequently, the foundation above it becomes unstable.

For coarse sand above medium sand (CS-MS), the increasing of EPWP only occurs at depths greater than 0.35 m from FWL. Over time, the EPWP value becomes smaller up to a negative value. A negative EPWP value results in the pore pressure decrease, so that the effective stress increases. The increase of the effective stress makes the shallow foundation stable.

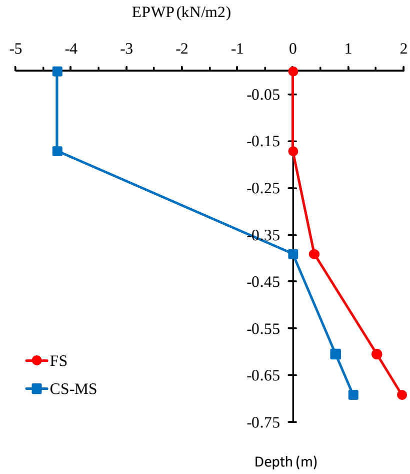

Fig.15 The EPWP on soil layers in the tank with upward seepage.

5. CONCLUSIONS

It can be concluded that sand in the Padang beach is dominated by fine sand compared to sand in the river. The dry unit weight of the beach sand is lighter than that of river sand. The upward seepage that occurs in fine sand can increase EPWP. Consequently, the pore-water pressure increases and the effective stress decreases so that the foundation becomes unstable. Meanwhile, the addition of coarse sand on medium sand can reduce the EPWP; as a result, the pore water pressure also decreases so that the effective stress increases and the foundation becomes more stable.

6. ACKNOWLEDGMENTS

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