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Settlement of residential houses supported by piled foundation embedded in expansive soil

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Abstract

The damage has occurred on residential houses built on expansive soils. The weight of the walls and roof of the houses is transferred onto pile foundations through suspended tie beams and columns, respectively. The typical pile used to support the house was 30 cm in diameter and it was penetrated into the depth of 600 cm. The slabs or floors were rested on the fills. This study was conducted to determine all potential sources that initiated the settlement and damages to the houses. Site investigation to each and every houses that experienced settlement and damages was conducted to gather and inventory the pattern of the cracks or damages. The result of site investigation showed that there were no damages induced by swelling, but the settlements and cracks were triggered by settlement, instead. It was also noticed that the settlement of piled foundations located on the area that susceptible to the water infiltration relatively larger than those piled foundation in the covered area. Therefore, it was concluded that, based on the analysis, the damages which occurred on the residential ordinary houses were mainly caused by the settlement of the piled foundations and the fills due to the soil softening.

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Keywords: expansive soils; settlement; crack; soil softening; residential houses.

1. Introduction

The demand of housing in urban area has been increasing in the last few decades. Accordingly, it requires large area of land for residentials and infrastructures. Several Real estates in Surabaya, the second largest city in Indonesia, have been expanding to the areas that consist of expansive soil formation.

The ordinary low rise housing, which is built on expansive soils require better and more comprehensive design

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due to its swell and shrink behavior. The expansive soil will swell when contact with water, and shrink when lose its moisture content. Due to seasonal climate change, the moisture content of soil at the upper layer changes. The depth of expansive soil to which its moisture content changes periodically by the seasonal climate change, is called active zone [1]. Based on the soil investigation in Surabaya – Indonesia reported by Testana Engineering, the thickness of active zone is about 5 m [2]. When the weight of a structure rested on the active zone is less than the swelling pressure of soil, the structure will heave and may experience differential deformation.

The consistency of expansive soil will soften when its moisture content increases and harden with losing its water content. In their research focusing on expansive soil in Surabaya – Indonesia, Tjandra et al. [3] stated that the seasonal wetting and drying cycles affects the undrained shear strength of soils, and furthermore it has an impact to the friction capacity and adhesion factor of pile foundation.

2. Wetting behavior of unsaturated soils

The wetting-induced softening behavior of the unsaturated expansive clay is crucial to understanding the rain-induced settlement of foundation and progressive slope failure in unsaturated of expansive soils.

Zhan et al. [4] investigated the softening characteristics of unsaturated recompacted and natural soils using suction-controlled triaxial tests. It was found that the wetting process for recompacted specimen generally showed ductile failure, while for the natural specimens exhibited a brittle failure similar to a heavily over consolidated soils, which is caused by the cementation effect of iron and manganese oxides. It was also stated that dilative behavior developed only for the natural specimen during wetting process. Ye et al. [5] identified that the magnitude of shear dilation of the unsaturated specimen depends on the confining pressure or suction, i.e. the dilation decreases with the increase of confining pressure and suction. It is also mentioned that, in low suction state, the cohesion of the specimen increases linearly with the applied suction.

Upon wetting, the failure of soil specimen was indicated by development of rapid shear strain in soil when the suction was reduced to certain threshold value. Along the wetting path, an increase in degree of saturation is related to the decreasing suction is associated with the flooding of soil voids with water. As a result, the normal forces at interparticle contacts decrease, thereby reducing the overall stability of soil skeleton. From the macroscopic viewpoint, both yield stress and shear strength of the soil specimen decrease Wheleer et al. [6].

According to Melinda et al. [7], at the beginning of the infiltration process, the soil deformation was small but matric suction decreased rapidly. When failure approaches, soil deformation increases sharply.

3. Typical ordinary houses

The typical low rise houses, which were studied, consisted of brick walls confined by reinforced concrete columns and beams. The weight of the walls was transferred onto pile foundations through suspended beam, which was supported by the piles. The floor was laid on the approximately 80 cm thick fill material. The schematic of cross section of the house is presented on Fig. 1. Typical diameter of pile foundation was 30 cm in diameter and it was penetrated into the depth of 600 cm (Fig. 2).

4. Soil data

Soil profile of the housing area is presented on Fig. 3. The soil formation is dominated by unsaturated clay layer. Based on the soil investigation report conducted by Testana Engineering, the existing soil layer consists of expansive soil with the active zone of 5 m (Fig. 4). The properties of soil is presented in Table 1.

Table 1. Soil Properties

Depth (m)	Classification	Wc (%)	Gs	γt (t/m^3)	Deg. of saturation S (%)	e_o	LL	PL	Cohesion (kg/cm^2)
2.5 – 3.0	CH	35	2.60	1.63	79	1.15	76	24	0.24
6.5 – 7.0	CH	32	2.60	1.68	80	1.04	87	26	0.55
10.5 – 11.0	CH	29	2.56	1.74	83	0.90	82	25	0.76
16.5 – 17.0	CH	30	2.60	1.74	83	0.94	66	23	0.78

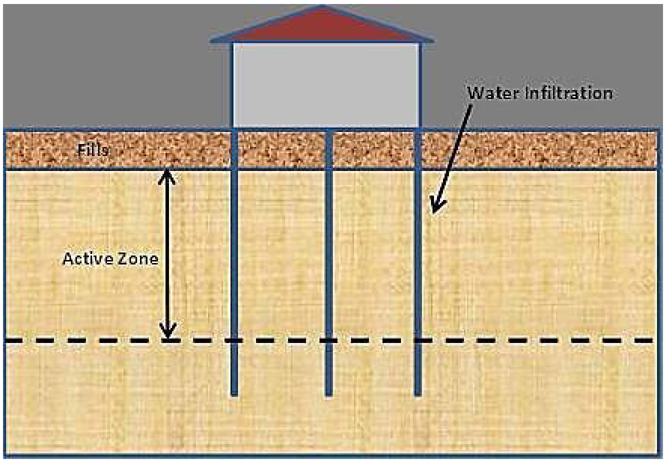

Fig. 1 Schematic of cross section

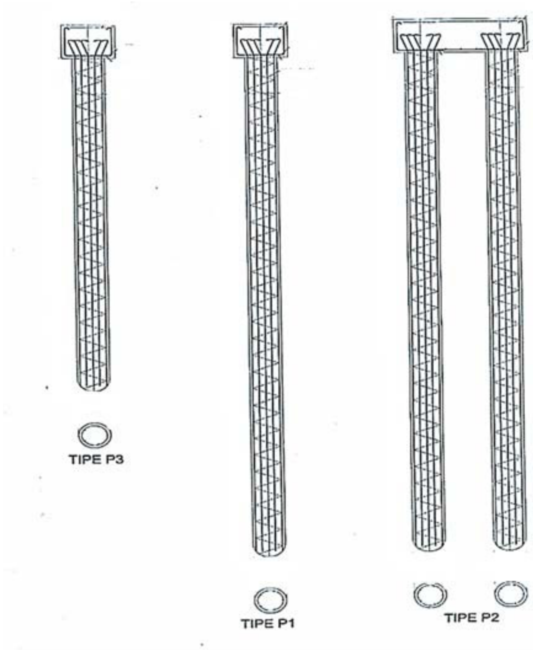

Fig. 2 Typical piled foundation

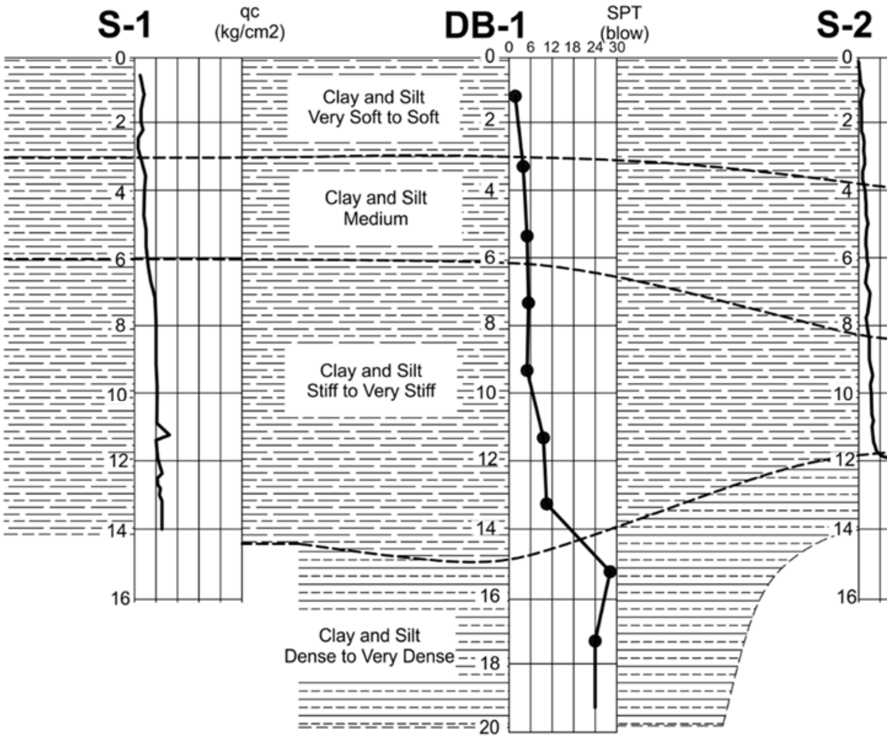

Fig. 3 Soil profile

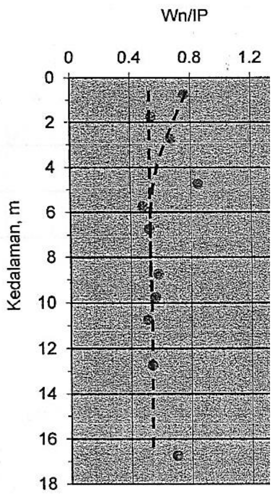

Fig. 4 Active zone

Fig. 5 Differential settlement of floor

Fig. 6 Gap between floor and wall

Fig. 7 Differential settlement of carport slab

Fig. 8 Crack and differential settlement of unreinforced carport slab

Fig. 9 Diagonal crack on the wall and ceiling

Fig. 10 Vertical cracks on the brick wall

Fig. 11 Poor detailing at beam-column joint

Fig. 12 Poor detailing of beam-column joint and horizontal cracks on the brick wall

5. Research method

Site investigation was conducted to identify, take documentation of cracks, and gather additional information from the owners. The observation was focused on the condition of the floors, pattern of cracks on the walls, detailing of joints, and source of water infiltration that potentially triggers heaving or softening of soils.

It was observed visually that settlement of the floor occurred in several areas, such as presented in Fig. 5 and Fig. 6, and the differential settlement of carport slabs as presented in Fig. 7 and Fig. 8. In addition, there were gaps between ceramic floor and the fill. It was indicated by echo on several areas of ceramic floor when the floor was knocked. In general, there were no indication of damage that initiated by heaving on the floors.

The diagonal cracks on the walls caused by the differential settlement between adjacent columns, where the settlement of one column relatively larger than that of another column. In several locations, wider cracks were noticed on the upper part of the wall and continue to the ceiling, as presented in Fig. 9. Crack was also observed on the neighboring wall after the house was demolished, as presented in Fig. 10.

Poor detailing of beam-column joints was noticed on the neighboring wall as presented in Fig. 11. Horizontal crack was also noticed on the wall due to the absence of column to support beam as presented in Fig. 12. These poor joints definitely reduced the stiffness of the walls when it experiences differential settlement

Important information was noted during site investigation. It was found that the perimeter walls, which located in the borderline with open ground experienced relatively larger settlement than those bordered by covered ground (neighboring house).

6. Analysis

By combining all available data that were collected during site observation such as pattern of cracks, construction drawing, and as built drawing of the damage houses, potential factors that contribute to the damage of the houses can be summarized as follows.

Site observation data showed that there was no indication of damage on the houses, which was triggered by swelling of soil. All data indicated that the damage was initiated by settlement (or differential settlement) of foundation and filling material. The expansive soil located in the active zone might experience swelling or heaving due to the presence of infiltration water, but it was relatively small compared to the settlement of the fill material. Therefore, there were no indication of cracks due to heaving or swelling of soil.

The thickness of the fill was ranging from 0.5 m to 1 m. Meanwhile, the length of the piled foundation was about 6 m. In other words, almost the entire length of the pile foundation is penetrated into the active zone. It means that bearing capacity of the piled foundation is vulnerable to the changing of shear strength of soil due to wetting-drying of soil layer in the active zone. The softening of soil in the active zone due to infiltration of water definitely will reduce bearing capacity of the piled foundation. Consequently, the piled foundation will experience settlement during wetting.

Infiltration of the water into the active zone is the main factor affecting the change of moisture of the expansive soil. Therefore, permeability of the fill and the potential source of infiltration water play the very important role in

triggering the damage of the houses.
The damage of the houses was also contributed by poor detailing of joints between beam and column. The rigidity of the brick wall would decrease significantly when the quality of the connection between beam and column that encased the wall is poor. As a results, cracks on will easily develop on brick wall when it experiences differential settlement.

Based on the aforementioned facts, it is safe to state that the damage of the houses mainly caused by soil softening rather than swelling of soil.

7. Conclusion

Based on the available data and analysis, it can be concluded that the damage of the houses is initiated by the following factors:

The fills were not compacted properly and less impermeable so it experienced relatively large settlement when flooded with water.

The length of the piled foundation was not adequate so that almost the entire length of the pile embedded in the active zone

The infiltration of water initiated softening of soil in the active zone at which the pile foundation was implanted. This softening process reduced the bearing capacity of the piled foundation that mainly rested on this layer. The reduction of bearing capacity of this piled foundation has generated settlement

Improper detailing of beam-column joints and joints between walls reduced the stiffness of the brick walls, so that several diagonal cracks developed on the walls due to differential settlement

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