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EFFECT OF PILE CONNECTIONS ON THE PERFORMANCE OF THE NAILED SLAB SYSTEM ON THE EXPANSIVE SOIL

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ABSTRACT: Expansive soils are clay that swells and shrinks with changing moisture content. The pavement that constructed on these soils is subjected to large uplifting forces caused by swelling. Hence, there is an imperative need to counteract the problem posed by these soils by devising innovative pavement technique. An attempt to develop a simple, easy to install and cost-effective alternative pavement system, nailed slab system was developed, wherein slab pavement will be connected to a reinforced concrete mini piles.This research examines the emerging role of mini piles in the context of reducing soil uplift movement and the nailed slab system (pile supporting slab pavement) a system for minimizing slab movement due to swelling in expansive soil by conducting small-scale experimental modeling in laboratories. The heave prediction also doing by using the correlation between change in moisture content and vertical strain from oedometer test data. The results of this study indicate that reinforcing the soil by using the mini piles can reduce heave of soil, and the nailed slab system experiencing smaller upward movement than an unsupported slab. The connection between the pile and the slab has a significant effect on the system's ability to withstand the upward movement of expansive soil. When pile and the slab were monolithically connected, the system shows the better performance than those the slabs with the free head pile. Thereafter a heave prediction analysis provided the amount of heave that slightly overestimates, but still good enough for a rough estimation.

Keywords: Expansive soil, The nailed slab system, Pile, Heave, Upward movement

1. INTRODUCTION

Expansive soils are clay that swells and shrinks with changing moisture content. This soil is the very common cause of pavement problems. Hence pavement which that constructed on such clay is subjected to large uplifting forces caused by swelling. Several attempts have been made to minimize the effect of the damage caused by expansive soil. These include removing and replacing the expansive material [1], physical and chemical stabilization [2], drainage management such as vertical and horizontal barrier, and use of special foundation techniques [3]. Among several proposed methods to reduce the damage caused by expansive soil, vertical reinforcement such as pile [4], micro pile [5], granular pile anchor (GPA) [6], Geo-pile [7], cement columns [8] and lime columns [9], are structures that used to counteract the upward force caused on the foundation by the swelling soils. However, most of them are found to have a certain limitation in terms of technicality, effectiveness and may be very costly [10].

Most studies in the field of the pile in reducing heave have only focused on the behavior of a single pile, not as a system. The nailed slab system was developed to be a simple, easy to install and cost-effective alternative pavement system, wherein slab pavement will be connected to the mini pile and its work as a system. The nailed slab system is a reinforced concrete pavement (slab thickness between 12 - 20 cm) supported by mini piles with the length of 150-200 cm and a diameter of 15 - 20 cm [11]. Fig. 1 illustrates the nailed slab system prototype. Although some research has been carried out on the nailed system on soft clay [12] and the influence on pile length on slab movement reduction on expansive soil have been studied [13], the mechanism by which this system on expansive soil has not been established, hence the performance nailed slab system in expansive soil need to explore.

This study set out to assess the effect of a group of the pile in reinforcing expansive soil, the behavior of the nailed slab system and the effect of pile-slab connection in the slab movement. In an attempt to understand the mechanism of the nailed slab system in arresting upward movement on expansive soil, small-scale experimental modeling in the laboratory was conducted. This paper also presents a heave prediction by using a simple method where the input parameter can get from the conventional oedometer test.

2. LABORATORY EXPERIMENTAL INVESTIGATION

The small scale experimental investigation was used to simulate the performance of the nailed slab system on the expansive swelling soils. The small-scale modelling was used because required small quantities of soil, it permits most test to be performed, more variables to be explored, the effect of varying the key parameter can study, lead to much more rapid results purely because the smaller size, shorter drainage paths, so the test duration may also be short [14].

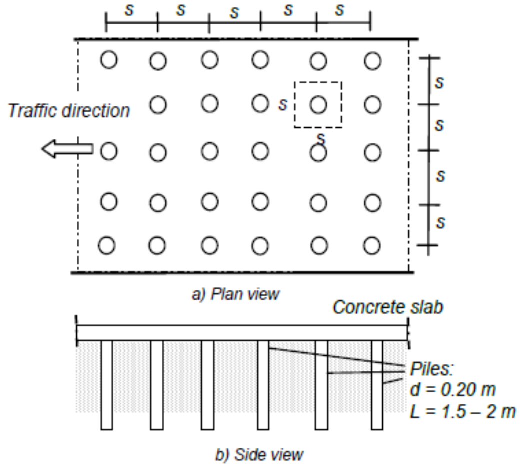


Fig.1 The nailed slab system [10].

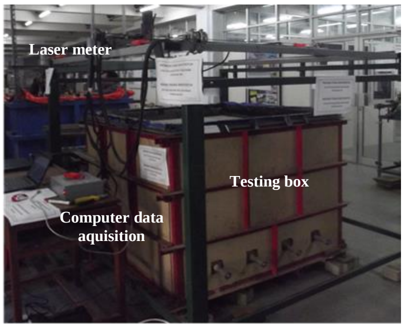
2.1 Material

An expansive soil from Ngawi, East Java was used for this study. The X-ray diffraction spectra gave the following mineralogical composition – montmorillonite: 64% and Andalusite: 35.9%. Disturbed sample collected from a location at a depth of 1-3 m below the ground level. The soil was air dried, pulverized and then sieved through a No. 4 test sieve.

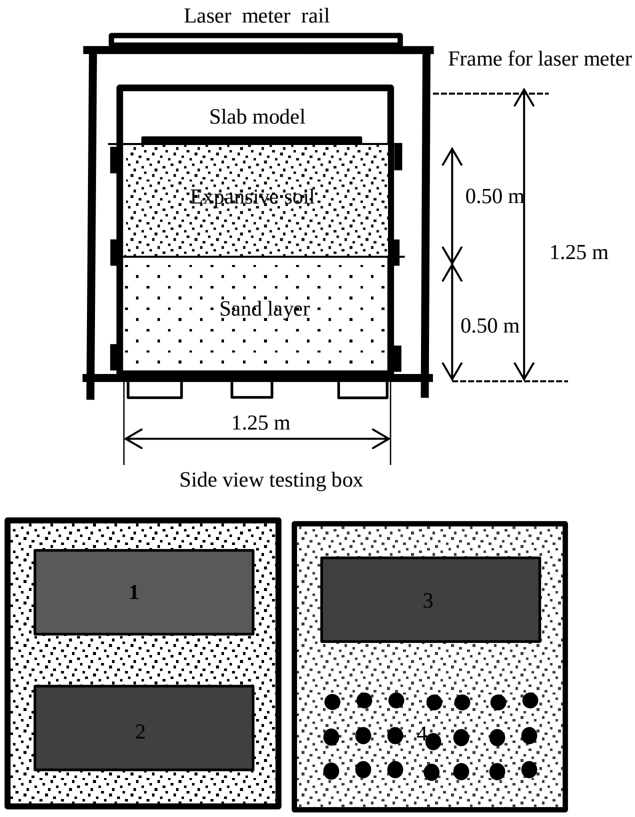
The laboratory test apparatus was developed to simulate field conditions. Steel box with the internal dimension of 1.25 x 1.25 x 1.25 m was used in this test. The photograph of the test setup and the positions of the laser meter is presented in Fig. 2(a). The inner wall of this box was made from fiberglass and was supported by 12 mm plywood and steel profiles to make the box very stiff. A cross-sectional sketch of the test setup is shown in Fig. 2 (b). The plastic layer was applied to the inner wall of the test box to minimize the effect of friction between the expansive clay and the walls of the testing box upon heave.

2.2 Properties of Representative Expansive Soil

The physical properties of the soil are presented in Table 1.



(a) Photograph of test box



where,
1. The nailed slab model
2. Slab with free head pile
3. Unreinforced slab (slab only)
4. Pile reinforced soil

(b) Schematic slab model on tests box

Fig.2 Test setup and illustration of the model.

The specific gravity (G_s) of the expansive soil specimen was determined according to ASTM D 854. The grain size distribution of expansive soil specimen was determined according to ASTM D 422. The Atterberg limits of the expansive soil specimen were determined according to ASTM D 4318. The Standard proctor compaction test was performed according to ASTM D 698, the expansive clay has a maximum dry density (MDD) of 12.25 kN/m^3 and optimum moisture content (OMC) of 35.5%. From swell-consolidation test based on ASTM D 4546 procedures, found that the soil has 25,73% swell potential and 200 kPa swell pressure. The swell-consolidation test conducted on soil sample with 15.5 kN/m^3 dry unit weight and 17% soil moisture content at 3.3 kPa surcharge pressure. Pile and plate models were made from Portland cement mortar, the average unit weight of the mortar was 2.3 g/cm^3, mortar pile reinforced by 1-2 mm galvanized steel wire, and slab reinforced by wire mesh.

Table 1 Properties of Soils

Soils properties	value
Specific gravity	2.64
Liquid limit (%)	94.39
Plastic limit (%)	34.58
Shrinkage limit (%)	11.63
Plasticity Index (%)	59.81
Percentage finer < 2μm (%)	96.32
USCS classification	CH
AASTHO classification	A-6-7
Compaction characteristics	
Maximum dry density (kN/m^3)	12.26
Optimum moisture content (%)	35.55
Activity	0.69
Free swell ratio (FSR)	2
Free swell index (FSI)	100

2.3 Test Program

2.3.1 Heave test

Heave test performed after the mortar slab reaches sufficient strength. The soil heaves triggered by adding the water from the top gradually. Approximately, 20 liters water added every day. The amount of the heave and deformation of the slab was determined in each model for comparison. To measure the vertical swelling of the expansive soils and deformation of the model due to water infiltration the laser meter was placed on the top of the testing box.

2.3.2 Variable Studies

The slab size was fixed at 30 x 70 x 2 cm, the pile diameter (d), pile length (L) and pile spacing (s) were fixed at 2 cm, 20 cm, and 10 cm, respectively. The connection between the pile and the slab was varied, as free head pile which is not connected between the pile and the slab, and fixed head piles that group of piles which are pile monolithically connected to the slab, later that called the nailed slab system. Not only, the heave that occurs in clay bed, but also the heave that occurs in clay bed reinforced with pile were observed. Briefly, the heave test measuring heave occurred on clay bed, pile reinforced clay bed, the deformation of the unsupported slab, the nailed slab system, and slab with the free head pile. Therefore for those purposed, its need two testing box to performed the test.

2.3.3 Compaction Procedure

The sand bearing layer is placed at the bottom of the test box, the sand layer consists of 50 cm depth of sand, leveled and compacted then expansive soil are spread above sand layer. The water content and dry unit weight of the expansive clay bed were fixed at 17% and 15.5 kN/m^3, respectively. The moisture content of 17% was chosen for the sake of convenient compaction. The expansive soil 50 cm thick was compacted in five layers. The uniformity in each layer is checked by measuring the unit weight and moisture content by using core cutter method. Thereafter, pile inserted in expansive soil bed with the arrangement as planned by pushing down the pile into the clay bed. In addition, for the nailed slab system model, steel wire pile reinforcement connected to wire mesh slab reinforcement, so that the connection between the pile and the slab was assumed monolith, and then, slab cast in place. For slab with the free head pile, there is no connection (free) between the slab and pile group.

2.3.4 Test Procedure

A slab was cast centrally on the group of the pile and the expansive clay bed. In case soil bed reinforced with the pile group, the pile group was driving in the central of clay bed. Heave was measured with the laser meter placed at the top of the test box. The laser meter connected to a computer data acquisition capable taking elevation of the of clay surface relative to laser meter position. The laser meter completed with the motor stepper that can move the laser meter in x and y-direction. The measurement accuracy of this laser meter is quoted at ±1 mm with the measurement range up to 100 cm relative to the laser meter elevation. This capability was considered ideal for this study. The laser meter can measure surface elevation in x-direction within interval 1 cm, and y-direction within interval 1.3 cm (0.5 inches). So the changes of the surface elevation of the entire area of the test box can be measured by laser meter day by day.

Before heave test began, the initial elevation of the clay surface was measured. The amount of the soil heave and slab deformation are calculated by the difference between surface elevation at current measurement to the surface elevation at initial measurement. The surface elevation measurement is continuously done with time until is no further significant displacement occurred. A heave time plot in the day has became made for each test and equilibrium was assumed to have been reached when the curve became asymptotic with the x-axis. The moisture content of the clay sample collected at the end of the test from various depths of clay bed. The water content of the sample was found to have confirmed to fully saturate and predicted vertical swelling of the soil and the slab model.

3. HEAVE PREDICTION

The practical method to predict the vertical movements of soil based on changes in water content proposed by [15]. The procedure tries to duplicate extreme moisture condition that soil will undergo in a testing box while under a constant vertical pressure. Significantly, these predictions can be made using only water content data and test data acquired with conventional and commonly available test equipment such as an odometer. Briefly, for predicting vertical strain (ε_v) as a function of the change in water content (Δw) at given total vertical stresses (σ_v), a series of test need to be conducted to determine the behavior of soil under field stress condition with changes in moisture content.

For testing under given vertical stress, ten remolded dry specimens were made, with water content and dry unit weight 17% and 15.5 kN/m^3, respectively. These water content and dry unit weight were same with the soil condition on a test box. The specimens were placed in odometer cells and then submerged to allow free access to water at atmospheric pressure. The maximum swell was measured with 2 specimens, The swelling was complete when the slope of vertical stain-log time curve decrease significantly, which occurred in about approximately 10 days under 3.3 kPa. The remaining soil specimens were then allowed to swell under the same stress for 6, 11, 30, 60, 240, 1440, 4320, and 14400 minutes. Before swelling was complete, these tests were stopped to determine the change in water content corresponding to measured intermediate strain levels. The swell curve for 10 specimens was almost similar but terminate at different times before the swelling is complete. These tests were duplicated for vertical stress 8.8 kPa and 12.5 kPa. These vertical stress were calculated from the surcharge pressure from the soil surface to the middle depth of clay bed on the test box.

The measured volume strains are plotted against the change in water content as shown in Fig.3. It was observed that linear relationship between vertical strain and the change in water content. At the higher vertical stress, the slope of swelling line decrease ($C_{\varepsilon,w}=\varepsilon_v/\Delta w$). A total surface displacement due to soil swelling is predicted by Eq. (1) as follow,

$$\Delta H = H_0 \times \frac{\Delta w \times C_{\varepsilon,w}}{100} \tag{1}$$

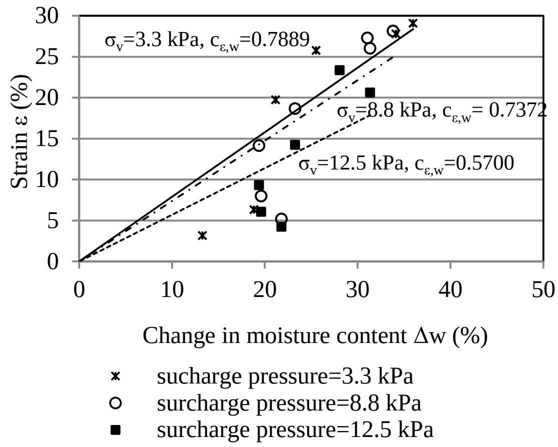


Fig.3 Response of strain to change in water content observed in swell test

4. RESULT AND DISCUSSION

3.1 Effect of Pile Reinforced Expansive Clay Bed on Heave Characteristics

The expansion of the soil measurements was obtained from laser meter on the surface of the expansive soil. Fig.4 shows the measured daily maximum vertical swelling in response to water inundation. With an increase in depth of wetting, an increase in the heave of soil surface occurs. As shown in Fig.4, the rate of soil heave that measured at testing box 1 and testing box 2 showed almost a similar pattern.

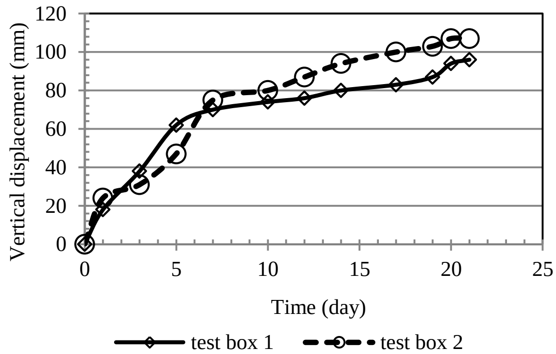


Fig.4 Rate of heave of expansive clay bed

As shown in Fig.4, the curve showed that initially, swelling against time, increase steeply, and then get the asymptotic condition after the seventh day.

Fig.5 compares the final surface heave of the swelling soil obtained from the heave test on testing box 1 and testing box 2. The unreinforced clay beds attained maximum heave (ΔH) of 108 mm and 98 mm respectively for testing box 1 and testing box 2 in 22 days. Fig.6 shows the moisture content in the initial condition and the final moisture content for testing box 1 and testing box 2. The change in moisture content at testing box 1 and testing box 2 almost similar, the average change in moisture content was about 30% for both two testing box. That factor indicated that the heave occurred on both clay bed almost the same, thus the model that is resting on the clay bed can be compared one to another.

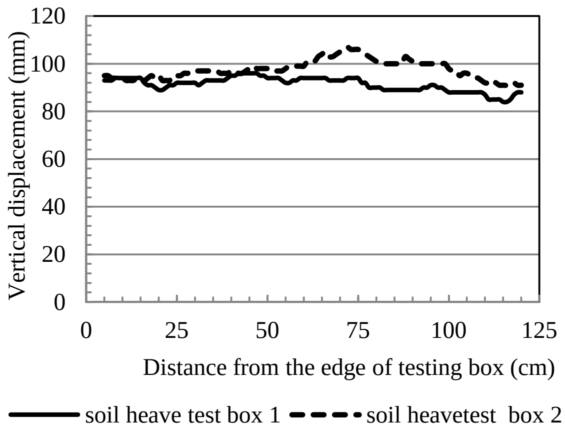


Fig.5 Heave surface of expansive clay caused by soil expansion at the end of the test

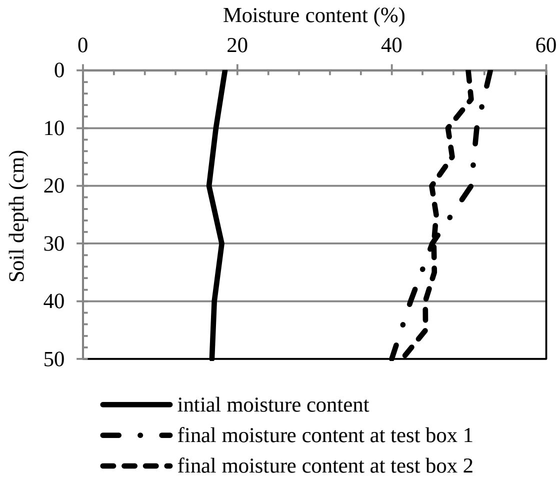
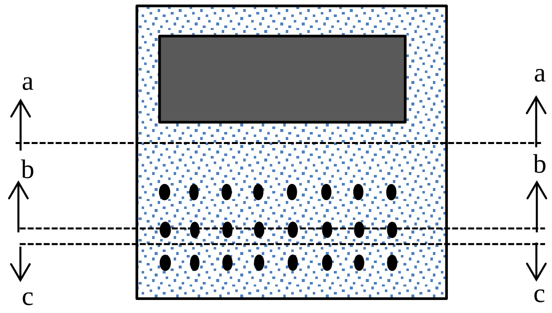
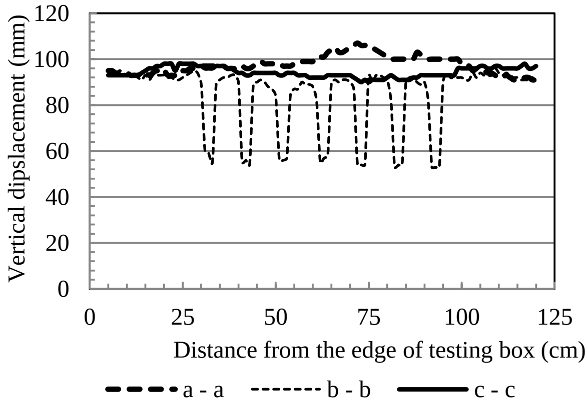


Fig.6 Moisture content of clay bed at the end of the test

Fig.7(b) compares the heaving surface of the unreinforced soil and pile reinforced soil on the cross-sectional position as shown in a plan view illustrated in Fig.7(a). It is apparent from this figure that the heaving surface of pile reinforced soil flatter than those unreinforced soil. No differential heave founded between the edge and the center of soil surface on the model of pile reinforced soil. In unreinforced soil, the biggest heave measured at the center of the test box and reduced at the edge.



(a) Plan view of the testing box



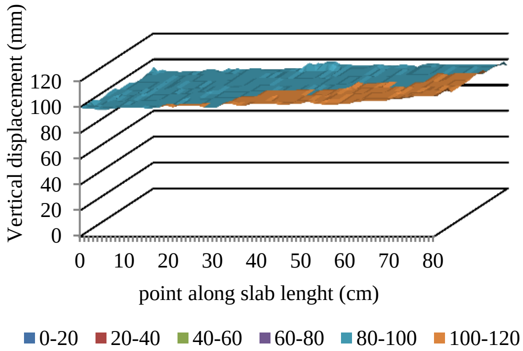
(b) Surface heave

Fig.7 The comparison surface heave of expansive clay bed at the end of the test.

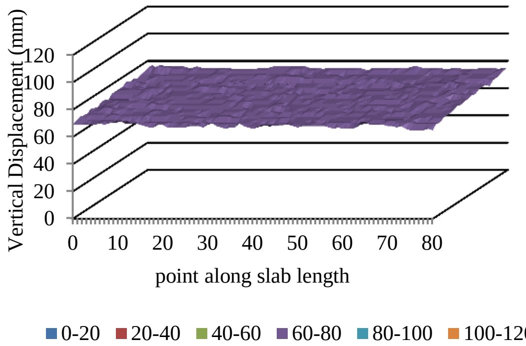
The result obtained from heave tests on pile reinforced soil is presented in Fig.7(b). When soil displacement occurs the pile is subjected to the uplift force due to the force of the skin friction between the soil and the lateral surface of the pile. Displacement of the piles governed by the heave of the soil over its thickness. In turn, the heave of the soil cover is not uniform along its depth. The greatest heave occurs in the upper regions of the soil while heave decrease at the depths. Therefore the upper layers strive to lift the pile to the maximum whereas the effect is minimal at the lower layers. Hence, the latter restraining pile uplift. Therefore, the restraining effect is a result of the nonuniform heave over its depth and self-weight of pile [4], its made pile experienced less uplift movement than the soil surrounding. Experiments showed that the displacement of soil around the pile is not uniform. The least heave was observed near the pile, which increased with increased distance away from it. This was made an arching effect, that caused the soil heave on pile reinforced soil least than unreinforced soil. The pile head experienced uplift movement about 57 mm, and the heave of the soil surrounding pile was about 90 mm, its mean the upward movement of pile head about 33% less than soil surface heave.

3.2 Heave Characteristic on Slab and Slab Reinforced with Pile (The Nailed Slab System)

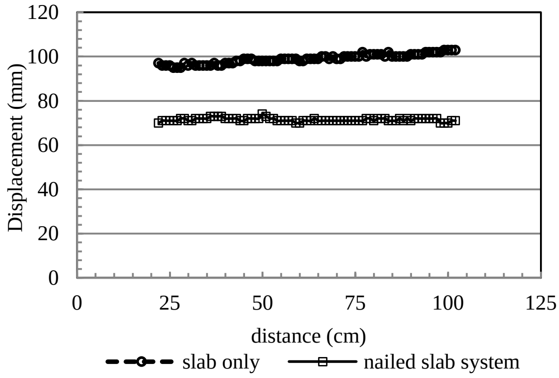
Fig. 8(a) and Fig. 8 (b) shows the displacement of the models due to swelling of the soil beneath the slab in 3 dimension. Fig. 8(c) shows the comparison between the displacement of the nailed slab system and unsupported slab



(a) Displacement occurred on slab only



(b) Displacement occurred on the nailed slab system



(c) Comparison of displacement between slab and the nailed slab system

Fig.8 Displacement of slab due to soil heave

The displacement of the unsupported slab was approximately 103 mm, and the displacement of nailed slab system, was 73 mm, supporting slab with pile can reduce displacement by 30%. Therefore, slab uplifted uniformly in the nailed slab model, where doesn't exhibit similar behavior on the unsupported slab model. In unsupported slab, differential movement on each edge was found.

It is now well established from a variety of studies that surcharge load or vertical load is essential to control slab movement if sufficient load is applied on an expansive clay, the detrimental volume increase can be controlled [3]. However, in this study, a possible explanation for this might be that the nailed system has more self-weight than the unsupported slab, that made the upward movement of the nailed slab system smaller than that unsupported slab. In this study, the self-weight of the unsupported slab was 0.1430 kN, while the nailed slab system was 0.1736 kN.

4.3 Effect of Type of Pile-slab Connection on Heave Characteristics

A shown in Fig.9, The upward movement of the nailed slab system were smaller than those slabs with the free head pile group. This result was attributed to the connection between the pile and slab when pile and slab monolithically connected, upward movement of the soil beneath the slab could move up the slab, this uplift pressure then transferred by slab down to the pile. This nailed slab system can not only reinforce the clay bed but also effectively resist the uplift force from expansive clay.

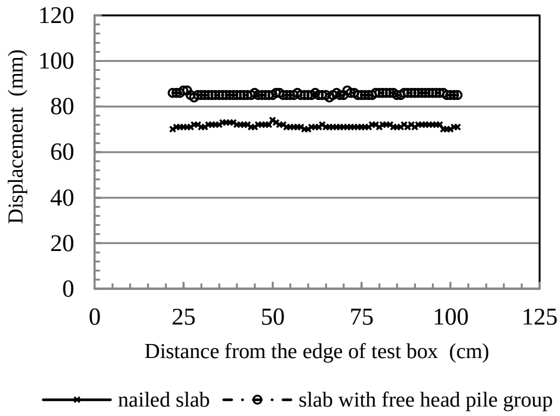


Fig.9 Comparison of displacement between nailed slab system and slab with free pile head group due to soil heave

Accordingly, the uplift resistance of the nailed slab system is a function of the self-weight of the pile-slab assembly, interface shear strength and normal stress developed during expansion on the soil surrounding pile and interaction between the slab-pile-soil that made the system stiffer. In the case of the slab with the free head pile group, the pile only reinforced the clay bed, where with those conditions, soil heave would reduce, but cannot resist uplift movement of the slab, due to the interaction between the pile and the slab does not form. As aforementioned, the upward movement reduction on the nailed slab system was 30%, on a slab with the free head pile group, the reduction was only 20% compare with the supported slab.

4.4 Calculation of Heave

The prediction of soil heave by using the method proposed by **[15]** with the consideration that this method was simple and the input parameter can get from the routine conventional oedometer. The vertical pressure calculated from self-weight of the slab and soil overburden pressure. The heave prediction calculated to the point at the middle of the clay bed. The calculation based on Eq. (1), and summarized in Table 2, were carried out the soil bed in one layer, the thickness was 50 cm. The swelling line ($C_{\varepsilon,w}$) based on Fig.2. However, the prediction of three conditions, ie soil heave, and unreinforced slab and the nailed slab system resting on expansive soil.

Table 2 Calculation of heave

type	Soil Thickness (Ho) (m)	Depth of Calculation (m)	Vertical Pressure (kPa)	Changes in moisture content (Δw) %	Slope of Swelling $C_{\varepsilon,w}$	ε_v %	ΔH Predicted (mm)	ΔH Measure (mm)	Differences between predicted-measured (%)
Soil	0.50	0.25	3.3	30	0.788	23.667	118.3	107	10.59
Unsupported Slab	0.50	0.25	8.8	30	0.737	22.116	110.5	103	7.35
Nailed Slab	0.50	0.25	12.5	30	0.570	17.100	85.5	73	17.12

A total surface displacement prediction was 118.3 mm, 110.5 mm, and 85.5 mm for soil heave, unsupported slab, and the nailed slab system, respectively. The differences between the heave prediction and heave measured were about 10%, 7%, and 17% for soil heave, unsupported slab, and nailed slab system, respectively.

5. CONCLUSIONS

The present study was designed to determine the role of a group of the pile, not only to control and minimize upward movement on expansive soil but also as supporting a slab resting on expansive soil. The following are the main conclusions,

1. This study has shown that significant differences were found between soil surface movement on unreinforced soil and the pile reinforced soil. The restraining effect of the pile is a result of the nonuniform heave over its depth and self-weight of the pile, it's made pile experienced less upward movement than the soil surrounding.
2. Supporting slab by using the mini piles has a significant effect on slab movement reduction.
3 When pile and the slab were monolithically connected (fixed), the system showed a good performance inability to withstand the upward movement of expansive soil. The nailed slab system where pile-slab connections were fixed, reduce displacement 30% better than that unsupported slab. Therefore the slab with the free head pile, the reduction was only 20%.
4. A heave prediction provided the difference between measured and calculated vertical displacement was under 20%.

The findings of this research provide insights into the effect of installing pile to control and minimize damage caused by soil heave. The relevant parameters such as the effect of diameter and the ratio between pile length to the depth of the expansive soil need to explore. The study needs to be extended to field-level study. The heave prediction considering only on moisture content changes at the specific vertical pressure, in fact, many factors should be considered for heave prediction.

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