EXPERIMENTAL STUDY ON SEMI-ASSEMBLED FLOATING FOUNDATION USING SEWER PIPES FOR LOW-RISE BUILDINGS ON WEAK SOIL WITH FILLING SAND LAYER

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Abstract:.
The paper presents experimental research on using a sewer pipe as a semi-assembled floating foundation for low-rise houses with soft soil having backfill sand above. Sewer pipes were placed in the backfill sand layer and sealed at the end with concrete slabs (foundation with closed-ended pipe). In addition, another sewer pipe, which was not bottom-sealed, but filled inside with compacted sand (foundation with open-ended pipe), was also studied for comparison. The results of static load tests on the natural soil and two types of foundations, including foundation with closed-ended pipe and foundation with open-ended pipe, showed positive settlement-decrease effects, especially for the first one – the floating foundation with closed-ended sewer pipe. Compared with the foundation having open-ended sewer pipe, the bearing capacity of floating foundation is 4 times higher and the settlement is 5 times lower. Semi-assembled foundations using closed-ended sewer pipe and open-ended sewer pipe can be put into practice. Depending on the workload, we can choose the appropriate foundation type.

Keywords: *sewer pipe, floating foundation, filling sand, weak soil, static load test.*

1. Introduction

The Mekong River Delta has a high demand for low-rise houses having 4 floors or less. However, because the soil's surface layer is very weak and its thickness can be up to 15m, even more than 30m; the construction conditions are difficult and the foundation becomes costly. In the case of construction sites having filling sand above soft soil, the foundation may suffer from excessive settlement due to consolidation, which causes construction deterioration.

Using sand to level on soft soil has both advantages and disadvantages in construction. The sand layer will act as a form of load and a drainage boundary which makes the soft soil layer below the settlement consolidated. The settlement of sand leveling areas after the first 2 years can reach from a few dozen centimeters to more than 100 centimeters depending on the thickness of the leveling. The consolidation of soft soil may cause the shallow foundation to settle or cause negative friction to pile foundations [1, 2]. However, if the ground level has been leveled for a long time, and the remaining consolidated settlement is negligible, the upper-level sand layer is very convenient for laying shallow foundations.

According to a survey by the authors, some of the foundation solutions commonly applied to low-rise houses in the Mekong Delta provinces include: Conventional reinforced concrete pile foundation with a size of 200mm or more is driven into relatively firm soil layers at a depth of 20 to 40m; Mini-pile foundation with a small size of 100 to 150mm and length of below 10m; Weak soil is improved and compacted with split stone piles which have a size of 100 to 150mm and length of less than 2m and are driven by the water erosion method; Weak soil is improved and compacted with tea-tree piles. All suggested solutions have their own advantages and disadvantages [3].

Recently, Nguyen et al. [3] tested reinforcing the weak soil with sand leveled by short-length cement-soil columns applied to low-rise houses. The columns formed a buffer at the bottom of the foundation which allowed reducing the impact the stress causing settlement has on the underlying soft soil layer. The initial experiments showed positive results on improving the load-bearing capacity and decreasing the instant settlement of the foundation. The results of the static load test showed that the method of soil reinforcement with cement-soil buffer increased the load-bearing capacity of the shallow foundation by more than 3 times, and the instant settlement of the foundation reduced by up to 5 times compared to that of the unreinforced soil.

Nguyen et al. [4] also experimented that type of soft soil with D-BOX soil bags solution. Filling sand collected at the experimental site was put into D-BOX soil bags, placed on the foundation pit and then compacted. The results of in-situ plate load tests on non-reinforced soil and reinforced soil by 1 and 2 D-BOX layers showed that the D-BOX bag significantly increased the soil load capacity and reduced the settlement. The load capacity can be increased by 2 to 3 times and the instantaneous settlement can be reduced by more than 2 times. This solution can save a lot of labor and materials, thereby reducing the cost of foundation, suitable for low-rise buildings or rural roads.

In this study, the author tested the method of using short length sewer pipes with close-end to build semi-assembled floating foundation for low-rise buildings. Static compression test results showed that this floating foundation has good technical efficiency, reducing settlement and enhancing bearing capacity.

At the same time, this is a good solution in terms of environmental and economic factors.

2. Overview of floating foundation

2.1. Overview of floating foundation

Floating foundation is defined as the foundation type in which the weight of the structure is approximately equal to the weight of soil and water in the soil excavated for foundation [5,6]. The principle of floating foundation is shown in figure 1.

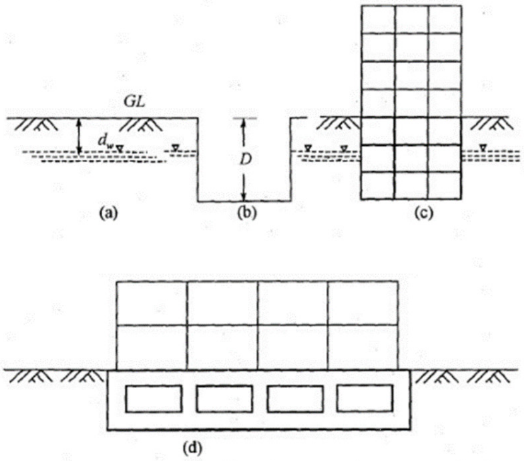


Figure 1. Principle of floating foundation and floating raft foundation (d).

As shown in Figure 1, if the building weight is equal to the soil and water's one brought up, the total vertical stress at depth D does not change between the finished time of construction (Figure 1c) and before foundation excavation (figure 1a). Since the groundwater level does not change, so there is no effective stress change and the structure will not settle completely if there is any possible transition from stage 1a to stage 1c without going through an intermediate stage 1b. However, it is not feasible. In state 1b, the soil can no longer remain its original state due to construction and may be detrimental to the structure.

Floating foundation can be used for following cases:

Case 1: If the soil under the foundation is capable of bearing but the differential settlement exceeds the allowable level, the floating foundation is used to reduce the differential settlement;

Case 2: The soil at the bottom of the foundation is weak and at risk of damage due to the very small shear strength, while the good soil layer lies at a great depth. In this case, the floating foundation is used to reduce the stress on the bottom of the foundation to below an acceptable level.

Floating foundation can be used in the form of single foundation, raft foundation, box foundation, pile foundation, pillar foundation or combination of the above types. To create the buoyancy of the foundation, it is possible to create a hollow foundation or use lightweight recyclable materials such as a hollow plastic box, a hollow ball or a foam inside the foundation block [7].

Terzaghi (1943) proposed the following formula to calculate the foundation depth Dc for case 2:

$$\mathrm{D_c} = \frac{5.7s}{\gamma - \left(\frac{s}{\mathrm{B}}\right).\sqrt{2}} \tag{1}$$

Where, γ: soil density, $s = q_u/2$: soil shear resistance, B: foundation width, L: foundation length.

Skempton (1951) suggested the following formula to calculate D_c based on excavation failure [8]:

$$\mathrm{D_c} = \mathrm{N_c}\frac{\mathrm{s}}{\gamma\mathrm{D} + \mathrm{p}} \tag{2}$$

Where, N_c Skempton load capacity coefficient, p live load.

The floating foundation can be used for low-rise or high-rise buildings. In the world, there are many high-rise buildings (15-25 floors) that use floating foundations effectively [9]. Floating foundations are usually structured in the form of a hollow box or box foundation (Figure 1d) which is as well as light and stiff [7]. In Vietnam, floating foundation has been applied methodically in the housing project in Bac Ha, Hanoi [10]. The townhouses have 4 to 5 stories in size built on very weak geology including mud and weak clay layers on the surface with more than 30m of thickness. The solution is to use the reinforced concrete box foundation on the bamboo pile. The foundation bottom is placed at a depth of 2.5m. The floating foundation in this project shows a high efficiency with a small settlement and little impact on surrounding construction.

To construct foundations in general, as well as floating foundations in particular, the following ways can be often used:

(1) Digging foundation hole with sloping talus;

(2) Digging foundation hole with temporary piles for stability (eg larsen sheet).

(3) Digging foundation hole with permanent piles for stability (bored pile or precast pile).

As mentioned above, at the excavation stage as shown in Figure 1a, due to the amount of soil excavated, the vertical load decreased and there was an uplift effect of the soil (Figure 2).

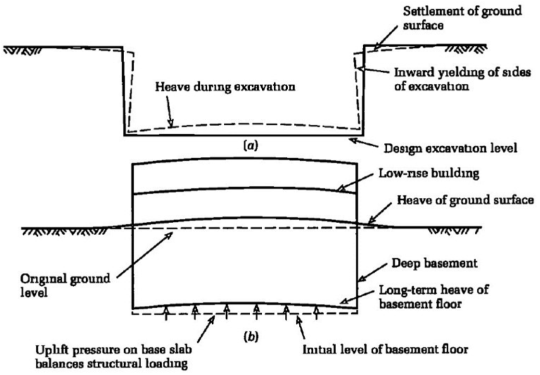


Figure 2. Soil movement around the excavation hole for low-rise buildings, (a): at the time of excavation, (b): at the time the completed construction [11].

The soil uplift at the bottom of the excavation hole should be calculated and its impact on the structure should be limited. The formula for calculating soil elevation according to Baladi [12] as follows can be used:

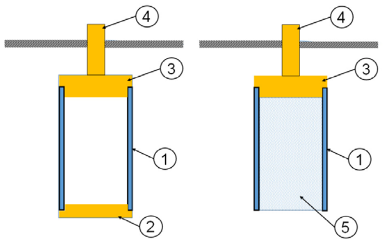
$$\delta_\mathrm{E} = \Delta_\mathrm{strip}\frac{\gamma\mathrm{d}^2}{\mathrm{E}} \tag{3}$$

Where, δ_E: elastic uplift, Δ_{strip}: coefficient depends on the width of the excavation hole, γ: soil density, d: depth of the excavation, E: modulus of soil deformation during unloading.

2.2. Floating semi-assembled foundation using sewer pipe.

In the Mekong Delta, there are many sewer manufacturing factories, from which the idea of using sewer pipes as foundation for low-rise buildings can be applied to soft ground in general and weak soil with sand levelling in particular.

Semi-assembled sewer pipe foundation is structured as follows (Figure 3):



(a) (b)

Figure 3. Structure of a semi-assembled foundation using a sewer pipe: (a) foundation with closed-ended sewer pipe, (b) foundation with open-ended sewer pipe. (1): Pre-manufactured sewer pipe, (2): a concrete slab that covers the bottom of the sewer, (3): The manhole cover is also the foundation footing, (4): the column neck, (5): compacted sandy soil.

Pre-manufactured sewer pipes are brought to the construction site, buried in the soil by digging soil in the pipe or digging holes. After the sewer pipe has reached the design depth, the pipe bottom is covered with reinforced concrete panels. Proceeding to pour the manhole cover with reinforced concrete. The thickness of the manhole cover is large enough to be the foundation footing at the same time.

Since the sewer is hollow, light and considered as a floating foundation, the construction using the method of applying inside the pipe is simple, required no holes-digging, which also causes less disturbance to the surrounding soil and the soil below the foundation bottom. Depending on the workload, it is possible to build a single foundation or trip foundation on many adjacent sewers.

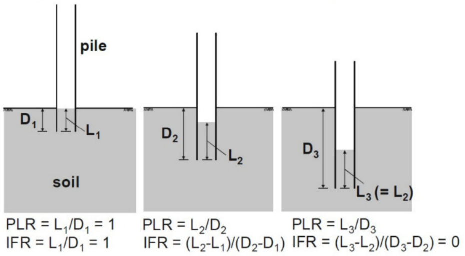


Figure 4. Illustration of PLR and IFR definitions.

Another type of foundation using sewer pipes is also suggested in this study is the sewer foundation with open-ended. Instead of a bottom seal, the tube bed is completely compacted with sand. At this time, the load capacity of the foundation can be seen as that of the pipe piles without bottom sealing. For the pipe piles without bottom sealing, two indicators are given:

$$\mathrm{PLR} = \frac{\mathrm{L}}{\mathrm{D}} \tag{4}$$

$$\mathrm{IFR} = \frac{\mathrm{dL}}{\mathrm{dD}} \tag{5}$$

Where, D penetration depth of pile (pipe) in soil, L length of compacted soil in the pile (pipe). dL: increase in length of compacted soil in the pipe bed corresponding to the depth of the pile dD. In other words IFR is the slope of the curve (L-D).

In the case the soil is filled up in the sewer pipe, we have PLR = 1, and if the soil cannot continue to enter the sewer pipe when the pipe penetrates the soil, we have IFR = 0. Many studies have shown that, the load capacity of the pile (pipe) will increase when the PLR index decreases [13]. The load capacity of the bottom sealing pipe pile will be greater than that of the non-bottom seal pile; when IFR = 0, the pipe piles without bottom sealing will work as the bottom sealing piles, with the load capacity equal to or greater than the bottom sealing pile [14,15].

Physically, the pile load capacity without bottom sealing is divided into two parts, the tube wall and the compacted soil in the pipe. The load capacity of the pipe bottom in q_{an} is inversely proportional to the slenderness of the H/D pile, while the load capacity of the soil fill is inversely proportional to PLR [16].

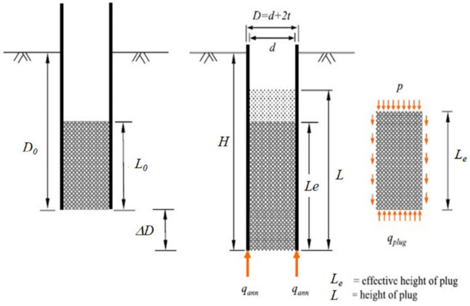


Figure 5. Load-bearing components of the pile (pipe) without bottom sealing.

3. Experiment program

3.1. Experimental site and geological conditions

Table I. Mechanical-physical properties of soil.

Filling sand layer	Thickness (m)	4
	Moisture content W (%)	26,2
	Wet unit weight γ_w (kN/m^3)	17,69
	Dry unit weight γ_d (kN/m^3)	14,01
	Specific gravity G_s	2,672
	Porosity	0,871
	Internal friction angle φ (^{0})	23^{0}24′
	Deformation modulus $E_{1\text{-}2}$ (kN/m^2)	8930,5
	Standard Penetration Test N (SPT)	6
Layer 1 : Sandy clay, brownish grey, very soft, very high plasticity	Thickness (m)	≥ 8m
	Moisture content W (%)	41
	Wet unit weight γ_w (kN/m^3)	17,17
	Dry unit weight γ_d (kN/m^3)	12,18
	Specific gravity G_s	2,667
	Porosity	1,148
	Internal friction angle φ (^{0})	6^{0}27′
	Cohesive force c (kN/m^2)	6
	Deformation modulus $E_{1\text{-}2}$ (kN/m^2)	1946,6
	Standard Penetration Test N (SPT)	2÷3

The experimental site is a residential area in Sao Mai, Binh Khanh 3, Long Xuyen city, An Giang province, with an area of approximately 50 hectares. The original soil in this area consists of layer 1 which is sub-clay silt and sandwiched with gray-brown sand with a thickness of 8m, and layer 2 which is medium gray sand with a thickness of 8 to 18.5m. By the time of the experiment (July 2018), the ground had been leveled with sand on having an average thickness of 2m for more than 10 years. It can be accepted that the consolidation settlement due to the leveling had finished. At the test site, the stable groundwater level is 1.5m from the surface.

The basic mechanical-physical properties of the ground leveling layer and soil layer 1 at the experimental positions are shown in Table I and figure 3.

3.2. Static loading tests at site

Figure 6. The process of installing well pipes.

The diameter of the sewers put into the experiment is 600mm. The length of the pipes is 1.5m, the wall thickness is 2cm. The static load test program includes static compression test of sewer pipes of 600mm diameter for two cases, with bottom sealing (closed – ended sewer pipe) and no bottom sealing (open-ended sewer pipe). The experiments are prepared as follows:

Sewer pipes are brought to the ground by the method of digging soil in the pipe. Lower the pipe to a depth of 1.5m above the natural ground, ie the manhole after bringing the sewer to the ground at the height of the natural ground (Figure 6). The distance from bottom of sewer to the soft soil layer is 4-1.5 = 2.5m.

For the open-ended sewer pipe:

- Add sandy soil taken at the experimental location to the sewer bed, compacted in layers with 25cm of each to a density of k = 0.9 until the the sewer is totally filled. The manhole is then sealed with a 5cm thick steel plate for static loading.

For the closed-ended sewer pipe:

- Flatten the bottom of the hole, pour a thin layer of lean concrete 3cm of thickness, then seal the bottom with a 10cm of reinforced concrete sheet. The bottom of the sewer is sealed to ensure the impermeability. Similar to the case of open-ended sewer pipe, the manhole is then sealed with a 5cm-thick steel plate for static loading.

3.3. Loading process

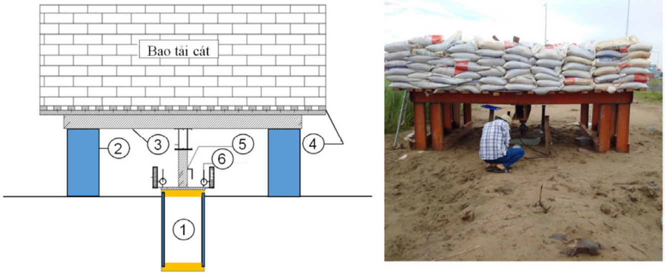
The static loading process applied to unreinforced and reinforced soils refers to the Vietnamese norm TCVN 9354: 2012 - Construction soil - Methods of determining the deformation modulus in the field by the plate load test [17]. The test preparation process is shown in figure 7.

The plate of the load test in this research has a square form of size 70.71x70.71cm and a thickness of 5cm (Figure 7). 4 dial gages, fixed on two reference beams, are used to measure the displacement of the 4 corners of the plate. These dial gages have an accuracy of 0.01mm and a margin of 50mm.

The hydraulic jacks can generate a maximum force of 200kN. The measuring range of the manometer is from 0 to 60MPa with an accuracy of 0.1MPa. The load is increased step by step, keeping each level of load constant until the displacement does not exceed 0.1mm per hour. The holding time for each of the subsequent load is no less than that of the previous load. The experiment was stopped when the stabilized deformation corresponded to the final load level or the total deformation reached 0.15d (d is the width of the plate). The unloading was conducted step by step. The time to keep the load of each level is 10 minutes; the last level holds 20 minutes.

The loading frame system (Figure 7) is made of profiled steel with sufficient bearing capacity and stability during the test. The main girder system made of I 300 x 150 steel bars with a thickness of 8 mm is connected with universal beams by bolts. The universal beam system made of I 250 x 125 profiled steel bars with a thickness of 8 mm is connected by bolts to support the counterweight on the platform. The main counterweight is sand-bags, each of which weights 35kg, a total of 1200 bags equivalent to 24 tons. The rest is the weight of the loading frame system.

The supports made of I 250 x 125 steel bars with a thickness of 8 mm are placed on steel plates (14 mm of thickness) lying on the ground.



(a) (b)

Figure 7. Schematic arrangement of testing (a) and photo at site (b). 1: sewer, 2: supports, 3: main girder, 4: universal beams, 5: hydraulic jacks, 6 : dial gages.

4. Test results and discussion

The experimental results of the static load tests on the un-reinforced ground and the foundation with open-ended and closed-ended sewer pipe D600 were gathered, as shown in Figure 8, 9,10 and 11.

From the pressure-settlement graph, taking the critical point for the bearing capacity corresponding to the point with a sudden change in curvature, the critical load capacity of the un-reinforced ground (original ground) is P_{gh0} = 160kN/m^2 (Figure 9).

The difference betwwen the pressure-settlement curves of the foundation on the sewer pipe with open-ended and the sewer pipe with closed-ended is significant (Figure 10). For foundation on the sewer pipe with open-ended, the load capacity of the foundation is only 50kN, corresponding to the point of sudden change in the slope of the curve. For foundation on the sewer pipe with closed-end, within the experimental compression load range, there is no significant change of slope in the curve. With an approximate way, it is possible to take the intersection point of two tangent lines of the curve, one line from the beginning of the loading and one line from the end of the loading, as the critical point of bearing capacity. This point corresponded to 200 kN of load. Thus the difference in load capacity is by 4 times.

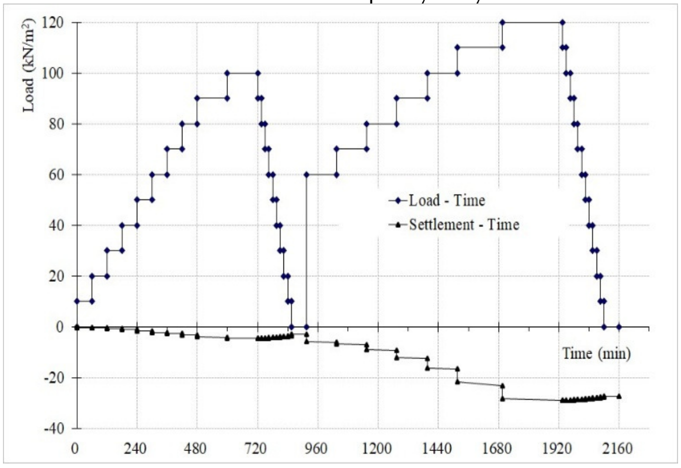


Figure 8. Load and settlement versus time of original ground.

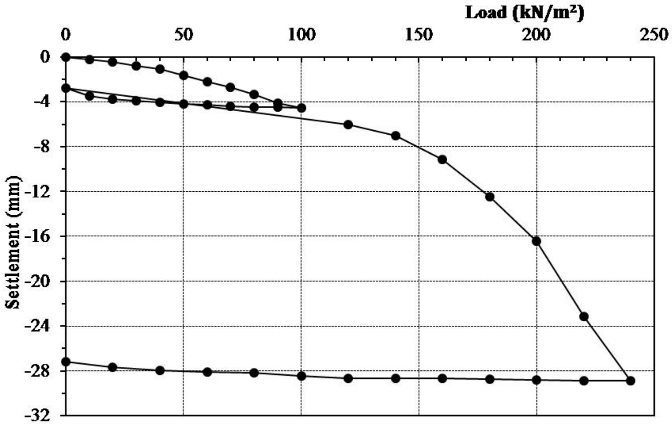


Figure 9. Settlement-load curves of original ground.

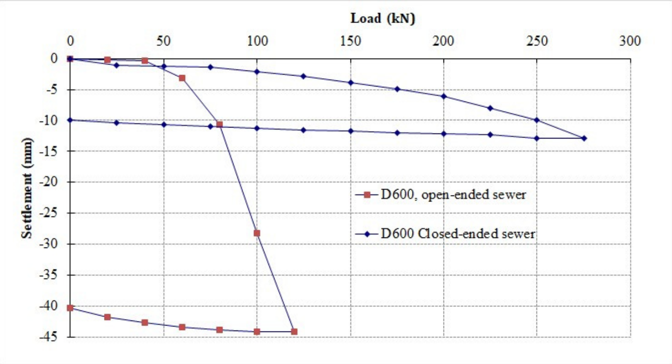


Figure 10. Comparison of the relationship between settlement-load curves of foundation on open-ended and closed-ended sewer.

In order to be able to compare the bearing capacity with natural ground, it is possible to convert the force exerted on the sewer foundation into distribution pressure.:

$$p = \frac{N}{A} \qquad (4)$$

Where N: compressive force acting on the foundation, A = π.D^2/4 cross-sectional area of the foundation bottom with D = 600mm being the diameter of the sewer pipe.

The pressure-settlement curves of the natural ground and of the open-ended and colosed-end foundations are shown in Figure 11.

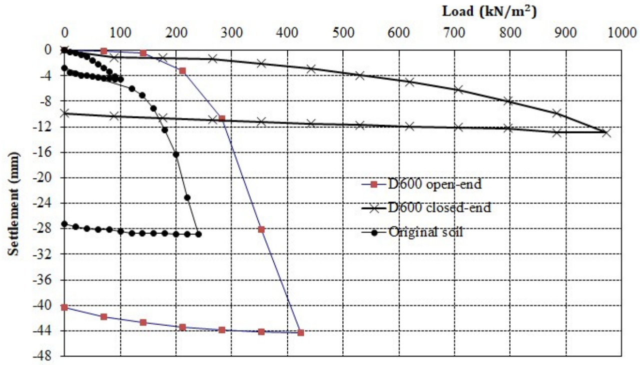


Figure 11. Comparison of the pressure-settlement curves of the natural ground and of the open-ended and closed-ended foundations.

Table 2. Comparison of the effectiveness of ground settlement reduction of the open-ended and closed-ended foundations at load level P = 240kN/m^2.

Item subjected to static loading	Settlement S_i at load level of 240kN/m^2	Effectiveness of settlement reduction comparing with original ground
Original ground	– 28.88mm	0 %
Open-ended foundation	– 6.5mm	78 %
Closed-ended foundation	– 1.3mm	96 %

In Table 2, the settlement of different items at the load of 240kN/m^2, ie the maximum load applied to the original ground is compared. At this level of load, the settlement reduction efficiency is great, especially in the case of closed-ended sewer pipe, and for the case of open-ended sewer pipe, the settlement is also greatly reduced.

However, although the sandy soil on the bottom and in the sewer bed of open-ended foundation has been compacted, the bearing capacity compared to the closed-ended foundation is significantly small for the following reasons:

- If compared with a solid foundation made of reinforced concrete having the same dimension and depth, the floating foundation with closed-ended sewer pipe will withstand a greater force, the increase in force capacity is exactly equal to the reduction in the weight of the floating foundation:

$$\Delta P = \Delta V.\gamma_{bt} = \frac{\pi D_t^2}{4}.H.25 = 9.2\ kN \qquad (5)$$

Where ΔP: the increase in load capacity between the floating foundation with closed-ended and open-ended pipe, ΔV: the difference in concrete volume between the two types of foundation, γ_{bt}: weight density of concrete, D_t: inner diameter of the sewer pipe, H: height of the sewer pipe.

- The load capacity of the floating foundation with open-ended pipe is much smaller than one with closed-ended sewer pipe. Although the soil has been filled and compacted in the sewer pipe bed, ie PLR = 1, the IRF > 0, the soil continues to enter the sewer pipe bed during loading, and the foundation with open-ended sewer pipe does not work yet like a closed-ended one.

5. Conclusions

In this paper, static compression test on weak soil with filling sand layer and two types of semi-assembled foundation using closed-ended and open-ended sewer pipe was performed. The results show that:

(1) The use of a semi-assembled foundation both with closed-ended and open-ended sewer pipe reduces significantly the settlement of the ground under the load. However, the effectiveness of the closed-ended foundation is outstanding because the base of closed-ended foundation is rigid, and more significantly, its weight is very light due to its hollow inside.

(2) In case of works with small load, it is possible to use the foundation with open-ended sewer pipe. However, to increase the load capacity of the foundation, it is necessary to compact the soil in the sewer bed as tightly as possible. Solid wastes such as concrete, broken bricks, and sand can be used to put into the pipe sewer. More experiments can be performed to determine the correlation between the degree of soil compaction in the sewer bed and the bearing capacity of the foundation.

(3) The semi-assembled foundation method using sewer pipes can save construction time, creating a hollow foundation with high bearing efficiency. Depending on the load of the project, single, trip or raft hollow foundations using closed-ended pipe can be used. To avoid water penetration, water leakage into the sewer pipe, plastic boxes, foam or an impermeable recycled material can be inserted into the sewer pipe bed.

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