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Study of Negative Skin Friction on Floating Piles Foundation Due to Long-Term Groundwater Extraction in Semarang Indonesia

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Abstract. The northern Semarang area is prone to a land subsidence problem as the underlying soil consists of a thick layer of normally consolidated clay which also exacerbated by groundwater extraction to meet water demand. The impact of a pile structure downdragged by the water extraction from two major aquifers that have been used for domestic consumption was investigated. A 3D-finite element analysis was performed to a raft foundation with steel pipe piles. The study used Banger polder data and soil characteristics based on previous investigations. The evaluation was done by comparing the results of negative skin friction (NSF) and total settlement within 50 years period under continuous extraction and one without. From the result, the corner pile located farthest from the pump mobilized NSF of 64% of the total negative skin friction which was highest than middle and interior-corner piles of 28% and 20%, respectively. The groundwater extraction was also found to contribute to almost double the settlement in 50 years in the non-piled area, from 0.24 m without extraction to 0.42 m accounted for. Also, the empirical $0.75L_{\text{pile}}$ for the maximum neutral point of the pile is in agreement in the result of this study.

1. Introduction

Semarang is one of the biggest cities located in Java Island Indonesia. From a recent survey in 2017, The city encountered one of the biggest increases in the population in its history as the city population increased from 1.5 million to almost 1.7 million in 2017 to 2019 [1, 2]. The growing demands of basic needs are inevitable, especially the domestic water demands for daily consumption. The water supply in Semarang is provided and is under PDAM (municipal water supply company) authority for both surface and groundwater sources. The water demand in the area increased yearly with the largest percentage of 83% or 37.50 million m³ that had been supplied by PDAM for domestic purposes [3].

According to DESDM (government local office of energy and mineral resources), in Semarang, 96% of the groundwater extraction is used for industrial purposes and the remaining 4% is for domestic purposes (e.g., public housing). In this project located in Banger, northeastern of Semarang, there are two confined aquifers found within the first 100 m below the ground (upper and lower aquifer). From both aquifers, the groundwater that is extracted via a deep well on the lower aquifer of the area is mainly used for industrial purposes and the upper aquifer is used via a shallower well dedicated for domestic purposes. There has been groundwater monitoring at this location conducted by DESDM [4]. From time to time,

as recorded on the monitoring well, the groundwater piezometric head on the monitoring well becomes lower due to this water extraction on both aquifers.

Groundwater extraction is known as one of the causes of land subsidence in Semarang especially in this project location in particular [5]. In this paper, the effect of groundwater extraction on both of these aquifers was studied. The study was focused on the impact of long-term groundwater extraction on the piles' foundation of building on the Banger polder based on finite element analysis. Finite element analysis can be used as a method to predict the impact of land subsidence due to groundwater extraction [6, 7]. Nguyen, Small and Poulos [7] showed the groundwater extraction can induce axial and lateral deflection on piles increasing piles' bending moment. In the long-term run of groundwater pumping, the piles may reach critical condition and get damaged. In this paper, the finite element model of land subsidence due to groundwater extraction was modeled using software called Plaxis 3D 2020 and the scope was limited to study the negative skin friction on the piles. In Banger polder, there has been a study on the impact of the landfill that includes groundwater extraction. It is mentioned that land subsidence in the area is significantly caused by the landfill instead (e.g., past and new reclamation) [8]. The groundwater extraction impact is rather small if compared to the overburden compressive load caused by the landfill. This paper discusses the extension of the research on the impact of the land subsidence in Banger to piled building solely from groundwater extraction and natural consolidation of the local area.

1.1.1. Land subsidence from a geotechnical engineering perspective

Land subsidence occurs worldwide and becomes one of the most scrutinized geohazards in an urban or rural area. Land subsidence is the occurrence of a vertical settling or the sinking of the ground surface [9]. Once the ground is settled, it is a non-reversible situation. It can occur naturally for instance due to the degradation of organic material in soils, or it can be induced by human activities such as underground mining or in combination [10, 11].

In civil engineering design, land subsidence can be taken into account for design consideration. For example is Jakarta Bay artificial islands reclamation design in which the land design elevation did consider the land subsidence from the nearby location which was recorded from digital measurement (e.g., GPS, InSAR) incorporated with consolidation settlement [12]. Full Modeling of land subsidence can be quite a challenge since many factors can influence this phenomenon. When a soil stratum or soils strata below the ground are compressed, the surface area is facing land subsidence. The discussion of how and why compression of soil occurs is widely discussed in the geotechnical engineering world. In the other words, land subsidence can be approached with a geotechnical engineering model. Bootsma, Kooi and Erkens [13] illustrated to model land subsidence in Netherland's peat by taking into account three main causes of compression on soils (compression by the degradation of organic materials due to oxidation, compression by shrinkage, and compression by loadings). A compression by loading in this matter is due to the change of effective stress in soil. For instance, an increase of effective stress due to embankment construction above clayey soil will cause settlement that consists of initial settlement and consolidation settlement (primary). Eventually, under constant loading, the creep settlement (secondary) on the ground will take place.

In theory, either primary settlement or secondary settlement is a result of a decrease in soil void ratio. Bjerrum [14] also describes how the primary consolidation can occur in nature as a result of an increase of effective stress (e.g., overlying natural sedimentation soils). Under a constant loading, clay deposit will encounter what is called creep settlement or secondary settlement at any time. Creep term here is limited to a time-dependent vertical directional settlement, as closely related to the primary consolidation of clays soil from a geotechnical perspective. In the simplest words, creep is the rearrangement of the soil grains over time resulting in a volume-change in the soil body. Creep theory was pioneered by Buisman [15] and Terzaghi [16]. The approach to explain the natural creep phenomenon in fine-grained and organic soil has been researched for the past decades [17-26].

Another example of soil compression by loading is groundwater extraction. The water that is extracted from the ground will reduce the pore water pressure on the extracted stratum increasing effective stress

below the remaining submerged soils. Hence the consolidation can take place in the first place at the overburdened soils. The more complicated case can also happen when the aquifer itself becomes compacted due to this water extraction. The famous land subsidence example is in San Joaquin Valley where the land subsidence was induced by continuous groundwater pumping over decades [27]. Water extraction in porous soil reduces the water amount in the soil void, and it will increase the soil compressibility resulting in the settling of soils above the aquifer.

1.2. Piles design subjected with negative skin friction

Piles foundation may be used for building in the location where the soft soils exist or when the load of the building is high (e.g. high-rise buildings). Designing a pile foundation in the soil where the surrounding soil settles or subsides requires extra attention to the bearing capacity of the foundation. Piles will experience downdrag as the soil surrounds settle.

1.2.1. Negative skin friction (NSF) on piles

Piles foundation needs to be designed to bear the building above the ground. To mobilize pile bearing capacity, relative movement of the pile to the soil is needed. Pile bearing capacity is mobilized through the positive skin friction (PSF) whereas piles are needed to be loaded from the top hence shear resistance and end bearing, respectively, on the shaft and pile tip are developed due to the relative movement of the piles to the soil (e.g., [28, 29]).

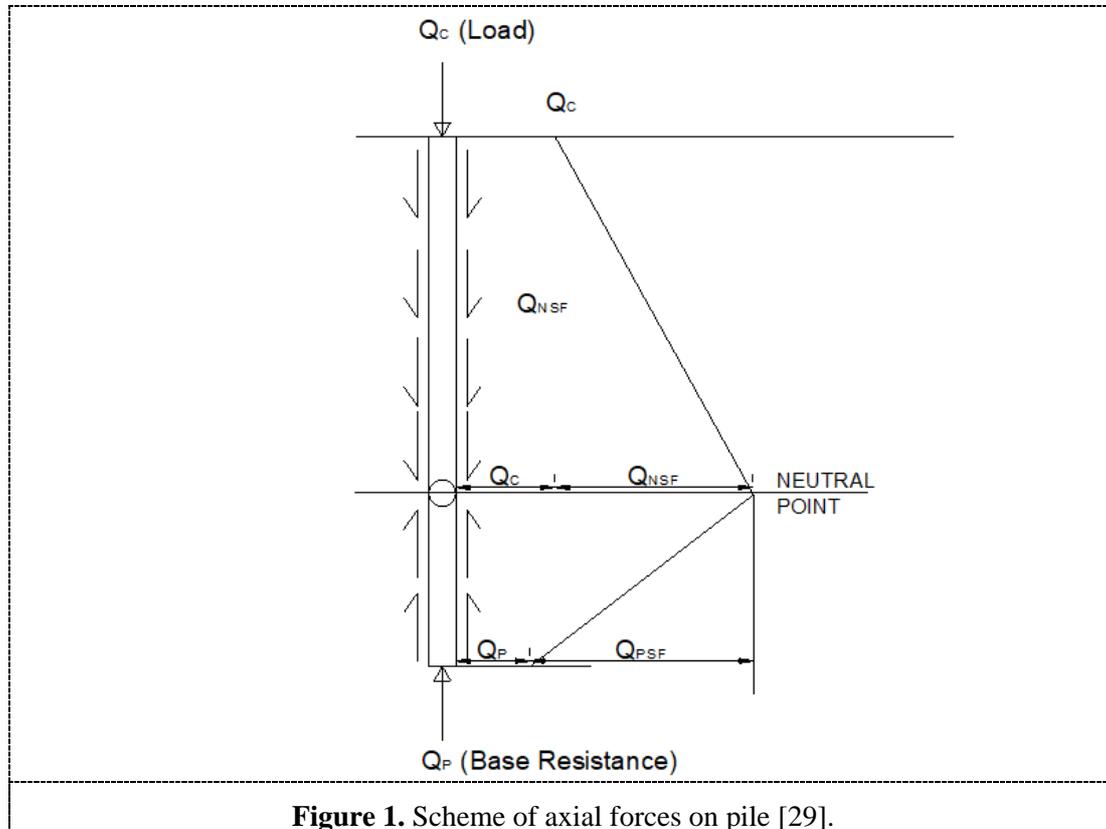
The opposite of positive skin friction (PSF) is known as negative skin friction (NSF). NSF is generated when the soil moves down relative to the pile. NSF will produce additional loading on piles as drag load develops on piles. Drag load on piles is caused by downdrag on the piles. Downdrag is a settlement of pile due to the settling of the surrounding soil. The effect of negative skin friction has been extensively studied over the past decades whether for single pile or piles in a group [30-32].

Consolidating soft soils or settling soils surround the structure's piles will induce drag load on piles. The drag load that is related to NSF is much more generated on the pile located in the outer corner compare to the pile located in the interior (inside the perimeter). This is known as the "shielding effect" in which piles located in the perimeter will act as a shield that reduces the amount of drag load and settlement that occurred on piles interior [33].

1.2.2. The practical design of pile subjected with NSF

When a pile is subjected to NSF, no bearing capacity or positive skin friction is developed along the pile skin until the neutral transition point between NSF to PSF is reached. This means, that the piles tend to experience settlement issues and hence piles need to be designed to rectify this. The transition point or neutral point plays an important role to calculate the pile bearing capacity. Axial load from pile top needs to be transferred to the soil via pile skin friction contact. This pile bearing mechanism is illustrated in figure 1. Indraratna [32] showed that the neutral point of piles shifted downward as the soil surrounding the piles settled/consolidated. At the early stage of construction, the neutral point position is relatively higher compared to the later time with a low degree of negative skin friction mobilized. After some time, eventually, the mobilized skin friction reaches critical value with the most minimum neutral point on the piles. This critical value means the highest possible mobilized negative skin friction that occurs on the pile's system and can be measured via in-situ tests such as static pile loading test. However, conducting a static pile loading test is very expensive and highly time-consuming and may only cost-effective for big projects. When designing piles subjected to NSF, a designer may consider following international standards such as SS CP-4 2003 [34]. For floating piles or friction piles on soft clays, SS CP-4 2003 suggests that the position of neutral point is 0.6 of the entire pile length ($0.6 L_{pile}$) and the degree of mobilization (η) of negative skin friction (Q_{NSF}) that resulting the down drag load is

typically 0.67 or 1 out of the total Q_{NSF} ($0.67Q_{NSF}$ or $1Q_{NSF}$). As another rule of thumb, the neutral point may also be taken as 75% from the total pile length or $0.75L_{pile}$ [35].



2. Geological setting on Banger

Semarang stratigraphy, in general, comprises three underlying formations, surficial deposit and sedimentary rocks, volcanic rocks, and intrusive rocks [36, 37]. From a geotechnical perspective, the sedimentary, volcanic, and intrusive rocks categorized as Pleistocene, Pliocene, and Miocene formations, respectively, are assumed to be incompressible layers. The surficial deposit is categorized as Holocene formation which is considered compressible. The surficial deposit is widely represented by river channel and beach deposit which is situated in a low-lying coastal area in northern Java, including also Semarang [38].

2.1. Banger polder's subsurface condition and hydrogeological setting

Banger polder is on the Semarang's polder located in the northeastern part of Semarang. Banger area is categorized as Java's surficial deposit formation. It is given the estimated soil profile which includes Banger area in figure 2, that this location is mainly dominated by clay and silt soils for the first 100 m below the ground surface. The estimated cross section is applied only for the natural formation on the area, the artificial landfill (e.g., past and present reclamation) is not included.

In Banger, a total of 2 aquifers has been discovered from some boreholes executed [8, 39, 40]. Figure 2 shows two major confined aquifers shallow and deep aquifer called alluvium and Delta Garang deposits aquifer, respectively. The first aquifer, the alluvium aquifer, is located at depth -19 to -25 below the ground surface. This first aquifer is confined by two aquitards in between this shallow aquifer layer. On the deeper part of the area, the Delta Garang aquifer is located at the depth -65 to -75 below the ground surface and is confined by two aquitards as well. Both aquifers are categorized as sandy soil.

Across Central Java Province, every groundwater extraction/exploration needs to have permission from a related authority. Information such as the location of the wells, extraction purpose, and volume of the extracted water is under DESDM. According to DESDM, the smallest and largest extraction discharge registered was 2 up to 200 m³/day, respectively [8]. As of 2020, the actual number of wells remains unknown.

Though the actual operating number of wells is unknown, groundwater monitoring is still being conducted. This groundwater monitoring is important to evaluate the water availability and the condition below the ground. This groundwater monitoring data is discussed further in section 4.

2.1.1. Banger Polder land subsidence

Besides due to its natural soil characteristics (e.g., consolidation and creep settlement of fine-grained soil), land subsidence in Semarang is induced by man-made activity such as groundwater pumping. The aquifers are compressed slowly as the water-extraction is commencing. Efforts of measuring land subsidence in Semarang has been started in early 1996 and has become national concerns since then [41].

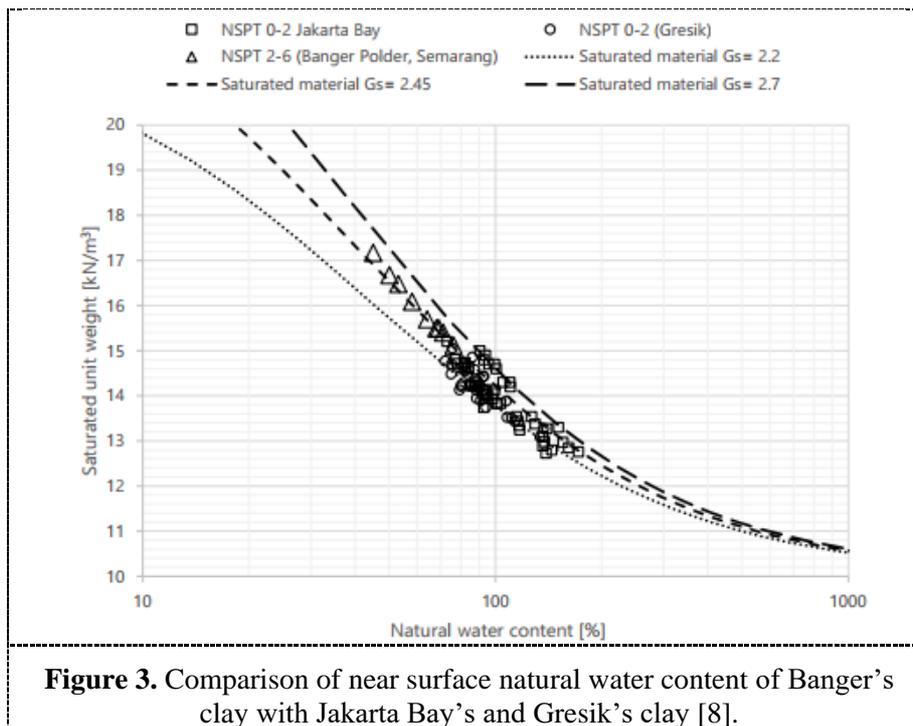
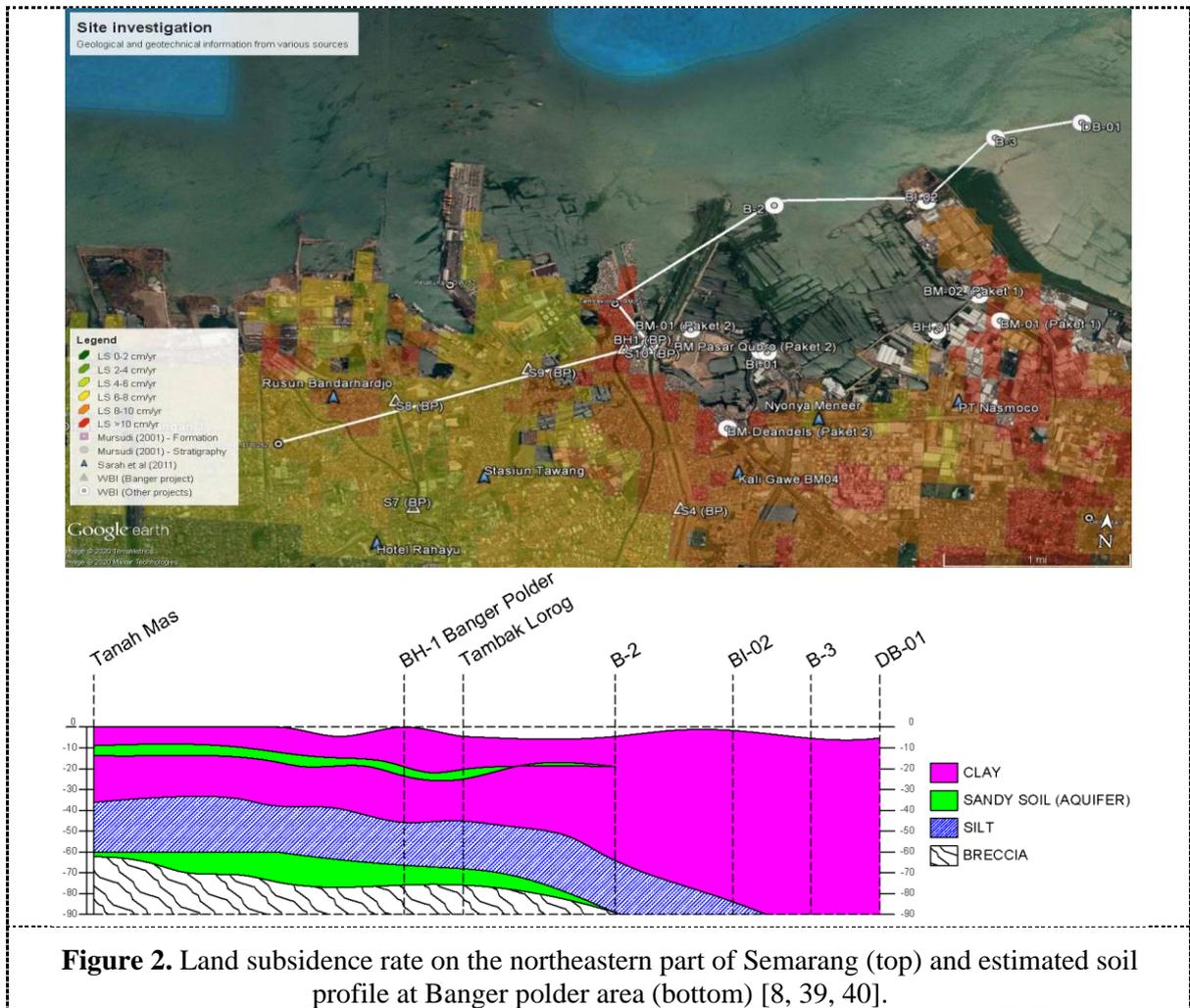
Some previous studies have shown the common impacts of land subsidence in Semarang [5, 42]. Other than the apparent ‘sinking’ of the buildings, coastal flooding called ‘rob’ (in Javanese) is the widely known impact of subsidence occurrence on the northern coast of Java island. The impacted area of the flooding is reportedly increased each year. The inundation due to the flooding deteriorates buildings and other infrastructures, such as roads, dikes, and bridges, in the form of cracking, tilting, and some level of differential subsidence. Several public facilities such as dikes and bridges no longer fulfill their functional requirement, being also slowly inundated. Additionally, these resulted in temporary or even permanent displacement of the affected population. The economic impact is also high, not only due to cover the costs of structural repair and/or rehabilitation of these facilities, but also losses from economic activities at the inundated industrial zone. The indirect impacts also include the living condition of the affected population, such as health and sanitation problems that are caused by poor drainage due to malfunction of the drainage system, increased seawater intrusion, and also substantial damaged and/or loss of wetland habitat.

The subsidence rate in the northeast part of Semarang varies, ranging from 0-2 cm/year to more than 10 cm per year. As given in figure 2, the Banger polder location is considered a yellow to red zone with a land subsidence rate of more than 6 - 8 cm per year.

2.1.2. Comparison of Banger Polder’s clay with other location

In construction practice, especially embankments, area dominated with clay soil needs to be treated extra since clay material is considered as highly compressible material. From a geotechnical perspective, high compressible soil such as clays and peats contain microvoids which are reflected as high porosity (n) or high void ratio (e) value [43]. Clay material is also able to retain a high amount of natural water content in its void. Natural water content (w_n) of soil is expressed as the ratio of water weight over the weight of the soil’s solid component in a volume of soil. In some areas in the north coastline of Java, the first few meters from the ground surface is usually clay soil. This clay soil deposited in the coastal region is often called marine clay which is characterized by ultra-soft soil stiffness and high water content [44].

The natural water content of near surface clay on the Banger polder area lies in the same trends if compared with the famous area such as Jakarta Bay or Gresik regardless of the variation of the water contents as shown in figure 3 [8]. In the Banger area, the clay generally has lower natural water content compared to Jakarta Bay’s and Gresik’s clay. This leads to higher undrained shear strength (c_u) of clays and may be proven by higher N-SPT value, as long as the plasticity index (I_p) value at the same comparable range. With the same stiffness consistency, Banger polder’s clays also have lower compressibility parameter of the clays compared to Jakarta Bay’s.



3. Basis of analysis

3.1. Overview of analysis

The effect of groundwater extraction can lead to aquifer compression in which can trigger subsidence above the compressed aquifer. This simulation of groundwater extraction with pumps was carried out to study the effect of negative skin friction on piles foundation on building nearby as the land subsidence occurs. Pumps were installed into the middle of two existing aquifers simulating 50 years of continuous pumping.

3.2. Model boundary condition and geometry

To conduct FEM analysis, some geotechnical and hydraulic parameters are essentially needed. The finite element model geometry and the related boundary condition for analysis are discussed in the following sections.

3.2.1. Soil profile for finite element analysis

The soil profile for finite element analysis was generalized from local boreholes executed in Banger polder [8]. A total of 6 soil layers consist of clays with stiffness consistency soft to stiff and two aquifer layers were defined for analysis. The soil profile for analysis is presented in figure 4.

3.2.2. Soil parameter for finite element model

The geotechnical parameters of Semarang soil were derived as presented in table 1. A typical ratio of C_c/C_r for soft (5.0-6.0) to stiff (7.0-8.0) clay was considered. A similar procedure in determining C_α , the typical ratio $C_\alpha/C_r=0.05-0.06$ (soft) to $0.02-0.03$ (stiff) were used. This ratio was based on engineering judgment and experience in the other projects in dealing with soft soil. All the layers were assumed to be normally consolidated (NC) as there was no indication otherwise. However, considering the q_c value obtained from CPT for layer deeper than -25 m MSL is very high for an NC condition, which typically comparable for stiff to very stiff clay consistencies. Therefore, for those layers, overconsolidation ratio (OCR) of 1.3-1.4 was used. For the layers above -25 m MSL or of soft to medium stiff consistencies OCR=1.1 was used, which is reasonable for the top layer developed from sedimentation [8].

Depending on the location, the thickness of each layer varies spatially. Considering the intrinsic parameter used for the initial check of consistency can be used to determine the thickness of those layers or to identify a new layer based on any borehole information at the site of interest

Table 1. Conventional soil parameter [8].

Layer	γ_{sat}/γ [kN/m ³]	C_c [-]	C_r [-]	C_α [-]	e_0 [-]	OCR [-]	C_v [m ² /s]
Very soft clay	14.0/14.0	0.65	0.15	0.015	1.7	1	7.4E-08
Very soft to soft clay	15.5/15.5	0.5	0.1	0.0125	1.4	1.1	6E-08
Soft clay	15.5/15.5	0.5	0.08	0.01	1.2	1.1	5.5E-08
Very stiff clay A	17.5/17.5	0.5	0.05	0.004	1.15	1.3	8.00E-08
Very stiff clay B	17.5/17.5	0.35	0.045	0.003	1.2	1.4	6.50E-08
Deep stiff clay	16.8/16.8	0.5	0.07	0.0065	1.3	1.4	6.00E-08

To identify and to quantify the causes of land subsidence in Semarang, finite element method software Plaxis was used to model a two-dimensional soil layer in Banger polder. After shortlisting the causes in the previous section, the Plaxis model is mainly used to explore the effect of groundwater extraction and consolidation. Plaxis allowed the user to perform a couple of flow-deformation method analysis that simulates deformation due to loading and groundwater extraction due to pumping. Thus in this section, the term subsidence is to represent the consolidation (primary) and creep settlement (secondary) and used interchangeably in later text. Table 2 presented soil parameters that were Plaxis-specific in the model. The compressible soil layer is assigned as soft soil creep model, whereas the sandy layers that were presumed as aquifers are modeled as linear elastic ($E'=8000$ kPa) [8].

Table 2. Soil parameter for finite element Soft Soil Creep (SSC) model [8].

Soil layer	γ_{sat}/γ [kN/m ³]	λ^* [-]	k^* [-]	μ^* [-]	n_{ur} [-]	$K_x=K_y$ [m/day]	K_z [m/day]	$K_{x,y}/K_z$ [-]
Very soft layer	14.0/14.0	0.103	0.0412	0.00229	0.15	8.50E-05	5.67E-05	1.5
Very soft to soft clay	15.5/15.5	0.087	0.0348	0.00217	0.15	5.19E-05	3.46E-05	1.5
Soft clay	15.5/15.5	0.099	0.0329	0.00225	0.15	4.20E-05	2.80E-05	1.5
Very stiff clay A	17.5/17.5	0.093	0.0233	0.00087	0.15	1.02E-04	6.78E-05	1.5
Very stiff clay B	17.5/17.5	0.071	0.0178	0.00065	0.15	6.28E-05	4.19E-05	1.5
Deep stiff clay	16.8/16.8	0.094	0.027	0.00123	0.15	5.19E-05	3.46E-05	1.5

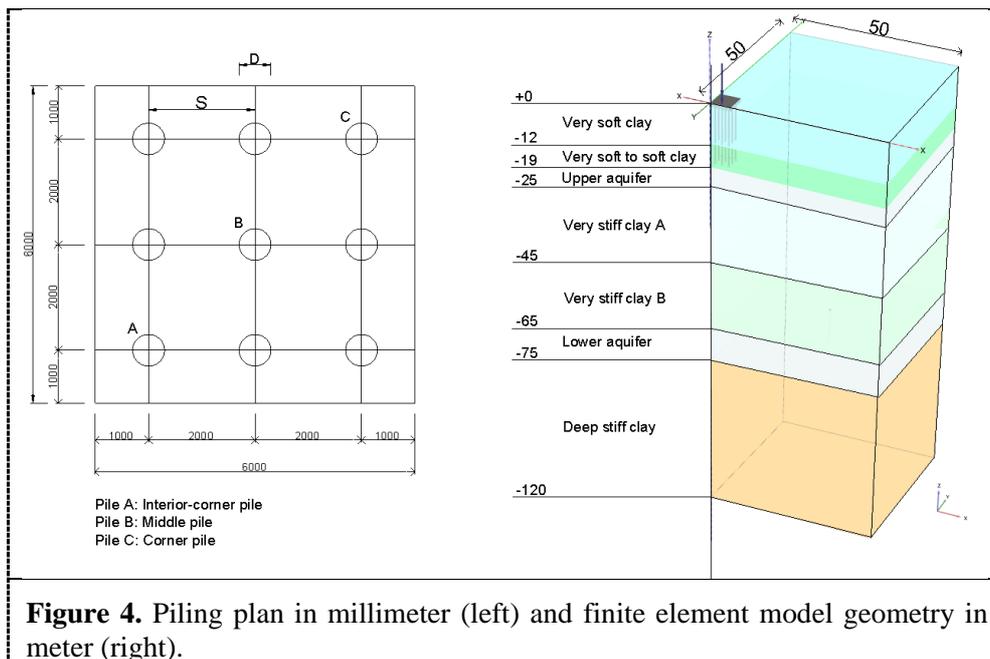
3.2.3. Pile foundation and finite element model geometry

The floating piles foundation model was designed using a simplified loading condition of 15 kPa area-load on the raft. This load corresponds to 1 to 2 story buildings. The raft sits on low-displacement piles of steel pipe pile (SPP) foundation with 610 mm diameter (D) and 3.5 mm thickness. These very low load and low-displacement piles were intended to produce a low strain on the soil-pile to minimize the undisturbed zone in the soil. In short term condition, the raft-pile foundation was designed to comprise the 25 mm maximum settlement from structural loading solely not included with the global area consolidation and creep settlement. In the long-term run, the consolidation and creep settlement will take place and it was modeled in automatic manners on finite element analysis with Plaxis. Raft thickness of 300 mm was used with a total of 9 SPP piles installed, altogether with 1 m excavation on the topsoil. The center to center of pile (S) distance is 2 m and hence S/D is equal to 3.3.

The soil model geometry was set to 50 x 50 x 120 m (length x width x depth) and the raft geometry was defined 6 x 6 x 0.3 m (length x width x depth). In the model, the raft-pile was positioned on the edge of soil model geometry. The geometry of the model can be seen in figure 5. This position was intended to study the effects of groundwater extraction and consolidation with creep settlement between the outer corner pile (C) and the interior piles (middle, B, and interior-corner, A). The groundwater pumps were installed in the middle of the soil model with the installation level at each corresponding aquifers both for the upper and lower aquifer. The first pump is located at X=25 Y=25 with Z_{top} at -19 and Z_{bottom} -25. However, the mentioned geometry is not related to the actual geometry of the pumps. This geometrical parameter was intended to produce a linear groundwater head lowering within the top to bottom of an aquifer. The same principle was applied for the bottom aquifer in which the pump was positioned at X=25 and Y=25 with Z_{top} and Z_{bottom} at -65 and -75, respectively. The discussion on how the groundwater pump was modeled is further discussed in section 3.2.4.

On the software, the piles were modeled as “embedded beam” with the predefined circular tube. In Plaxis 3D, the piles can be modeled as volume piles instead of embedded beam piles as an alternative.

However it is not simple to do the volume piles modeling, and hence embedded piles type of piles were chosen for simplicity and most efficient way to get structural and geotechnical internal forces results (e.g. quick interpretation of bending moment, axial forces, shaft friction, and foot forces on piles). The piles were installed at a tip level of -18, with the pile head elevation of -1 (17 m piles length). The piles were designed to act as floating piles penetrating the soft clay layer until 1 m above the upper aquifer. With this foundation system, the bearing capacity significantly relies on the shaft resistance instead of end bearing resistance. The shaft resistance is modeled as a “layer dependency” model with the maximum mobilized shaft resistance is calculated about 25 kN/m for all piles in all depth and the base resistance is calculated about 65 kN only.



Subsidence can occur as a result of the loss of soil organic matter (SOM) due to soil oxidation [45]. This type of subsidence factor occurs for organic soils such as peat soil. However, in this project, the biological complexity is not taken into account in the finite element model.

3.2.4. Groundwater head in the finite element model

Figure 5 presents the measurement result from the Anjasmoro station. The distance between the monitoring well and the Banger polder is up to 6 km (this station is one of the nearest stations and has the best data integrity than the others). Besides that, this station is chosen for analysis based on the similar subsidence rate on Anjasmoro to Banger polder as shown in the figure which is 6-8 cm/year. The effect of seasonal recovery in measurement was simplified with a linear trend of 0.4 m/year (4 kPa/year) head decrease rate. This head lowering rate was used to model the groundwater lowering as the impact of continuous extraction at the deep aquifer layer (Delta Garang aquifer). Additionally, groundwater head lowering at the upper aquifer (alluvium aquifer) was modeled 2 times lower at 0.2 m/year (2 kPa/year) on the basis of experimental condition. These groundwater head lowering was applied as a water pump model in Plaxis for both upper and lower aquifer.

The pumps were positioned in the middle of the 3D model (X=25, Y=25) to simulate the groundwater extraction. Although different water head in every stratigraphy layer can be specifically modeled in Plaxis (e.g. entire interested area from edge to edge model X=0 Y=50), though it requires a lot of time and computer resources to conduct such coupled flow-deformation analysis. Hence, the water head

lowering was simplified into groundwater extraction with pumps with the same water head declines rate as measured in Anjasmoro station for the lower aquifer (0.4 m/year) and for the upper aquifer 0.2 m/year was defined.

In Plaxis, the decreases of groundwater head by pumping that resulting in a decrease of active hydrostatic pressure (in kPa) is produced by inputting $Q(m^3)$ or pumping discharge, h_{min} (m) or the lowest elevation of the funnel, and pump filter length (m). Trial and error of Q , h_{min} , and filter length values were conducted to produce groundwater head lowering at $X=25$ and $Y=25$ of pump locations as presented in figure 6. The horizontal distance between pumps to the raft is about 20 m.

This model requires two types of water head, first water head is the initial water head of all soil layers before pumping commencement and the second is the groundwater head lowering of the aquifers. The default of -1 m piezometric head was defined as the initial piezometric head which was obtained from the local boreholes. As the pumping in the aquifers executed with constant discharge, the head in aquifers will decrease over time. The pumping process will reduce the current active pore pressure from initial time ($t=0$ year) to 50 years ($t=50$ year) as illustrated in figure 6. In 50 years, the active pore water pressure reduction on the upper aquifer is about 100 kPa (50×2 kPa) and for the lower aquifer is about 200 kPa (50×4 kPa) reduction of active pore water pressure.

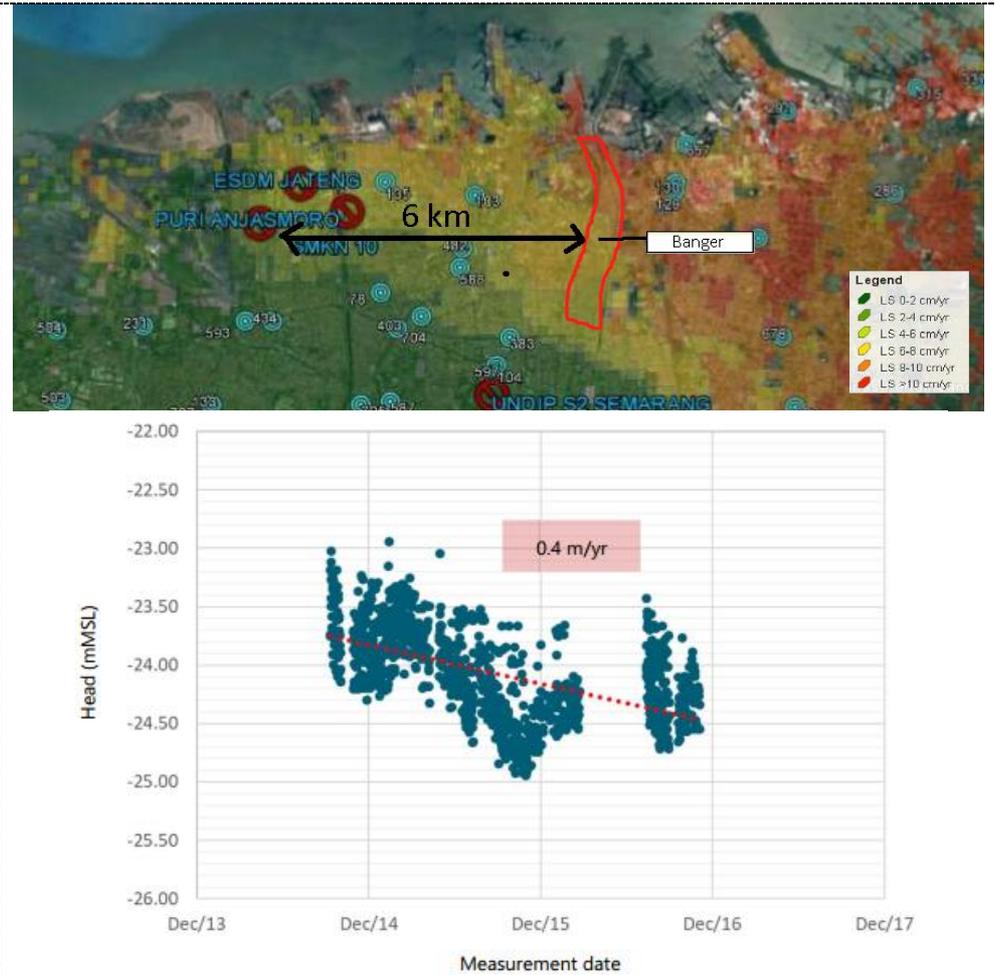
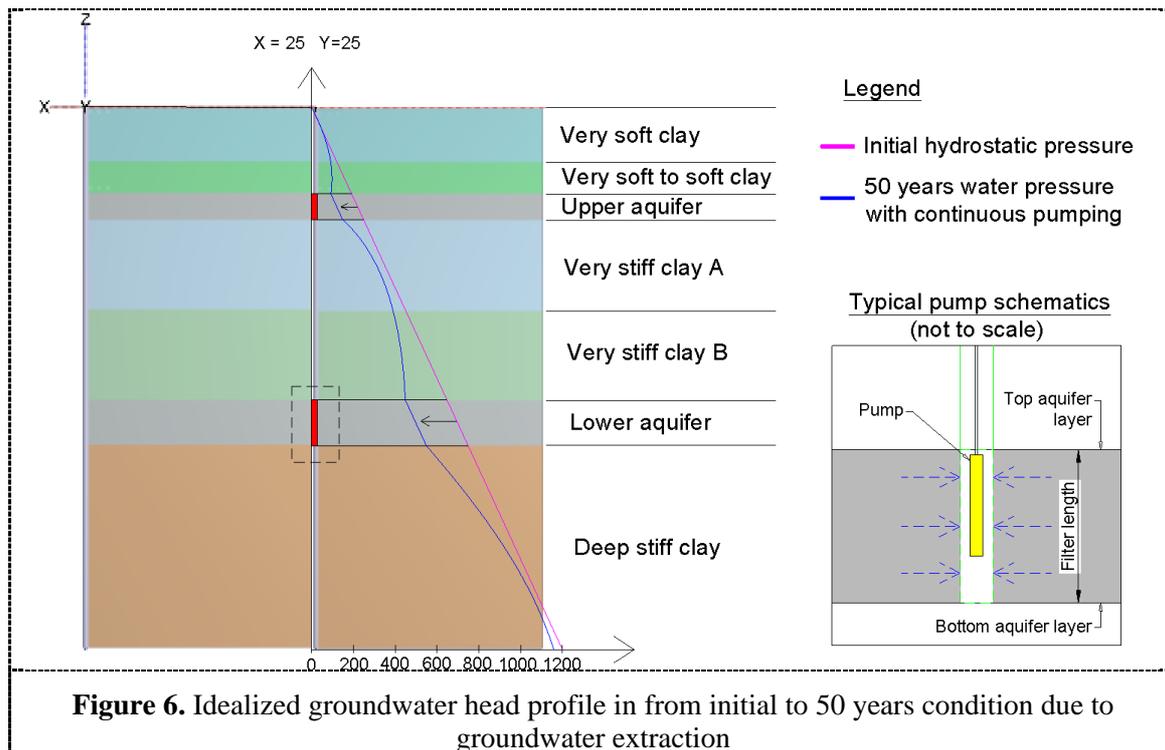


Figure 5. Distance between Anjasmoro to Banger polder (top) and well measurement from Anjasmoro station (bottom) [8].



4. Analysis results and discussion

The analysis was conducted with two analysis scenarios. The first model is foundation calculation within 50 years projection without the groundwater extraction. This is the best scenario since the settlement in the area is only affected by the consolidation and creep settlement that will take place for 50 years period. The second model is a calculation with groundwater extraction in 50 years. These two scenarios results are compared and discussed in the following sections.

4.1. Active pore pressure profile initial to 50 years condition

The pumps were positioned in the middle of each aquifer layer as shown in figure 6. To produce groundwater head declines similar as discussed in section 3.2.4, a constant head of 350 m³/day and 1000 m³/day need to be applied for the upper aquifer and lower aquifer, respectively. The pumps' filter length was defined to be equal to the thickness of each aquifer. The h_{min} (m) or the lowest elevation of the funnel was defined in Plaxis as similar to the top elevation of each aquifer. These simplifications were introduced to produce a constant reduction of active pore pressure profile on each aquifer. As illustrated in figure 7, it is depicted an initial active pore water pressure and 50 years active pore water pressure during pumping. With the constant discharge of the pumps, this will result in steady-state condition starting at a particular time somewhere between $t=0$ years and $t=50$ years. On the active pore water pressure chart, it can be seen that the pumping has also an effect on the changes of active pore water pressure in soil layers whether on top or bottom of each aquifer. This means that the reduction of active pore water pressure will lead to compression not only in the aquifers' thickness but also on the influenced zone due to pumping. However, the effect of water pressure reduction on the overlying and underlying soils on settlement amount is small. The settlement amount due to groundwater extraction is discussed in the next section.

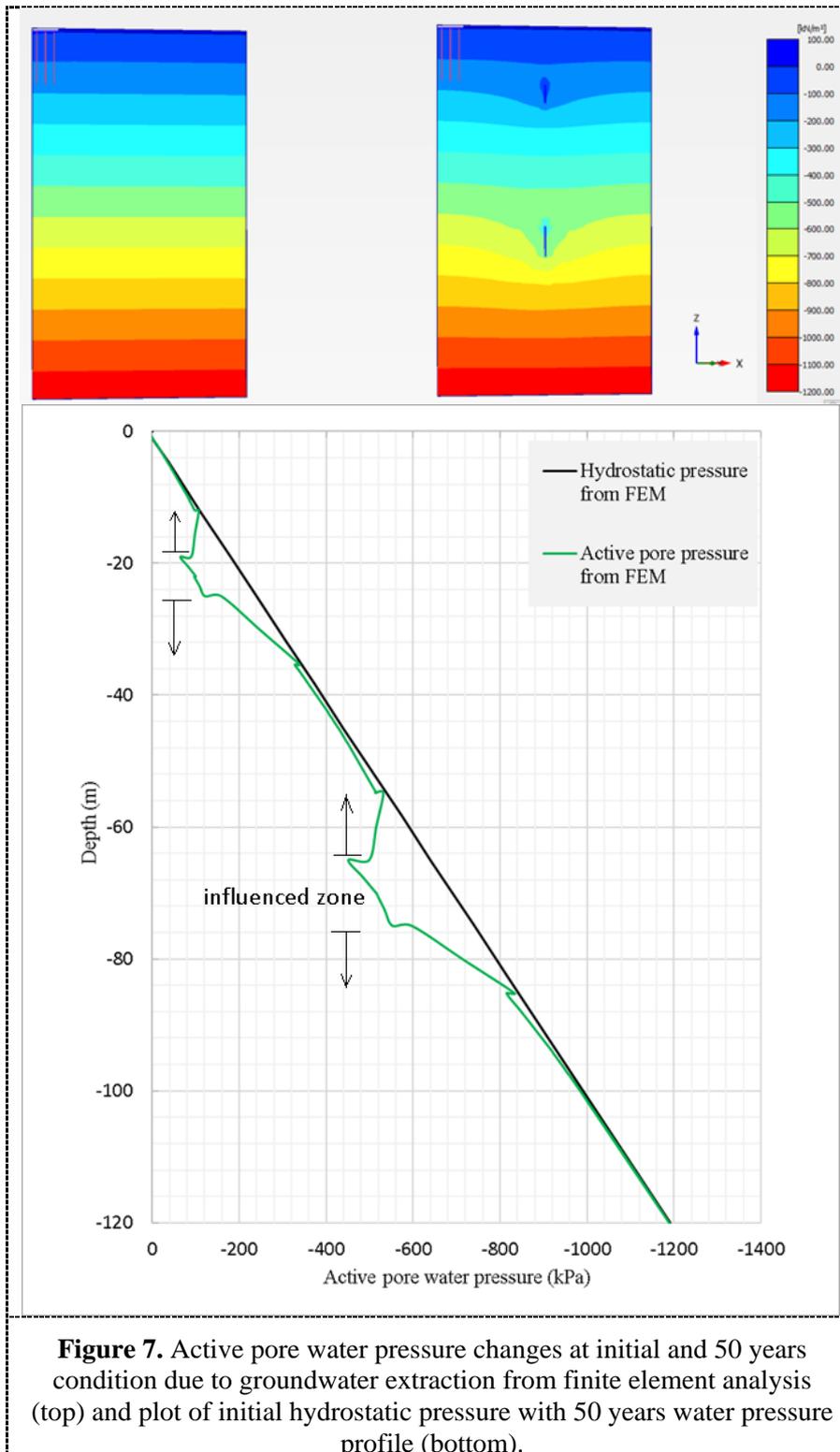


Figure 7. Active pore water pressure changes at initial and 50 years condition due to groundwater extraction from finite element analysis (top) and plot of initial hydrostatic pressure with 50 years water pressure profile (bottom).

4.2. Settlement comparison in 50 year

Natural settlement in Banger polder is mainly due to the nature of clay soil. Clay soil tends to have vertical creep settlement over time. In 50 years, from predictive analysis, the Banger polder will encounter about 0.24 m settlement and it mainly occurs on the surface. From figure 8, the creep settlement is dominant in very soft and soft clay above the upper aquifer. If the groundwater extraction

is commenced for 50 years, the settlement in the area will increase to 0.42 m. This is almost double the increase in settlement from 0.24 m to 0.42 m. The groundwater extraction will increase the settlement of about 0.18 m from the result of 3D FEM.

The increase of settlement of groundwater extraction is considerably low in number. Although, the actual land subsidence rate on the field is very high about more than 5 cm/year as discussed in 2.1.1. This actual land subsidence rate is a product of many factors, one of the most impacting is the landfilling on the surface. As illustrated by PT WBI [8], simulation of 1 to 3 landfill with groundwater extraction was performed to study the effect of a landfill on the subsidence rate in the Banger area conducted with Plaxis 2D axis symmetry model. With a 1 - 3 m landfill, the total settlement is increased to a range of 1 m to almost 3 m in 50 years, respectively. Without taking into account the landfill, it is mentioned that the land subsidence with groundwater extraction only was 0.48 m and it is comparable with the result in this study (0.42 m). It was also conducted a sensitivity analysis of the aquifer's stiffness to evaluate the amount of settlement on the surface. The compression of an aquifer is sensitive with the defined stiffness for the finite element analysis, thus 8000 kPa stiffness for the upper aquifer layer for this area is the most realistic value for this type of soil based on engineering judgment and NEN 6740 [8, 46].

Taking cross-sections from figure 8, it is depicted in figure 9 that the settlement on the raft surface area is reduced. The settlement on the raft surface is apparent to be lesser. The piles are limiting the land subsidence rate on the raft creating differential settlement between raft area and surroundings (e.g. point 1A vs. 1B and 2A vs 2B). Comparing point 1A vs. 1B, it has a differential settlement value of 150 mm (subtracting 250 mm with 100 mm) and 2A vs 2B has a similar value of 150 mm (subtracting 325 mm with 175 mm). The soil beneath the raft looks like hanging on the bottom raft. The reason is that in this model the pile-soil interface is set to R=1.0 to simplify the analysis. However, in reality, this is not always the case since soils beneath the raft can still settle creating a gap beneath the raft to the soil. The groundwater extraction from the upper aquifer will have a high impact on the surface settlement since the upper aquifer layer is compressed as the water from the aquifer soil's pore is gone. Water in the soil pores increases the stiffness of soil, when the water is reduced, the soil stiffness, in reality, is reduced as well. With the increase or even sustain overburden soil weight above the aquifer, the aquifer will have a tendency to compact. The extraction from the lower aquifer from the analysis also has an impact on the area. From depth -25 to -65 the settlement rate is 25 mm to 75 mm.

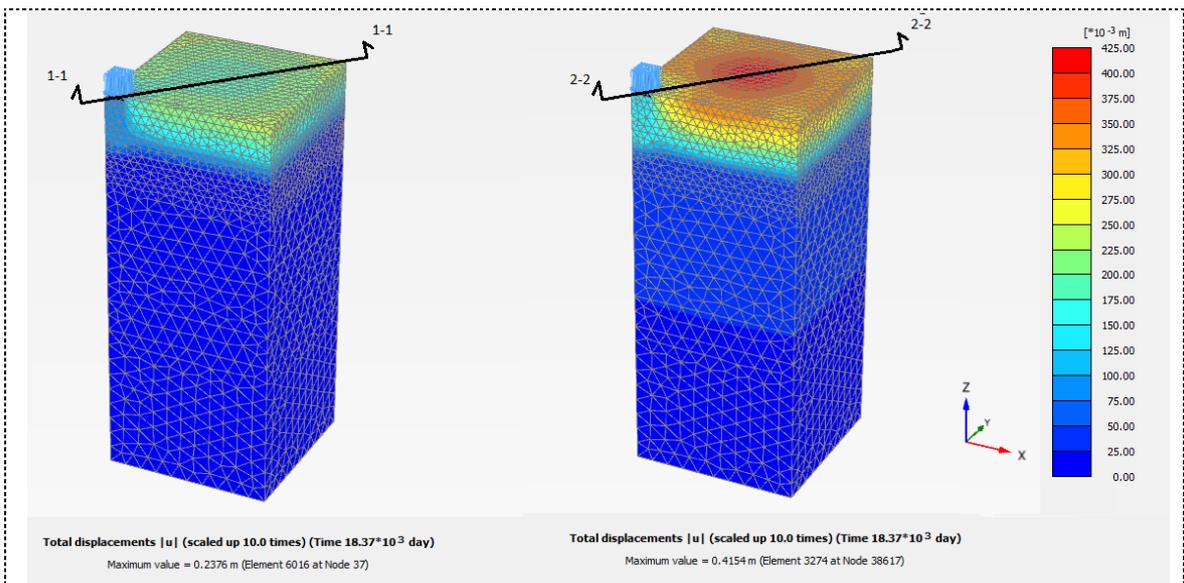


Figure 8. Settlement calculation without groundwater extraction (left) and with groundwater extraction (right) in 50 years.

4.3. Comparison of axial forces with vs without groundwater extraction in 50 years

Reduction of settlement rate as shown in figure 9 on the raft-piles area cost drag loads on the piles in which the settling soil surrounds the piles are dragging down the soil producing negative skin friction (NSF) on piles.

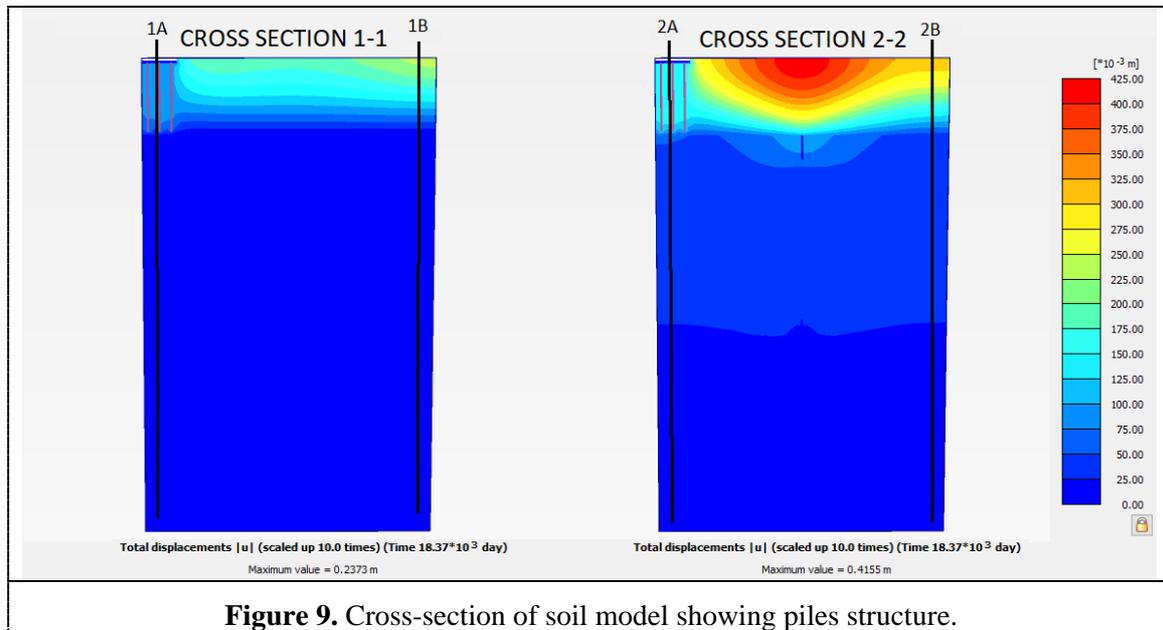


Figure 9. Cross-section of soil model showing piles structure.

Three piles were inspected: interior-corner pile (A), middle pile (B), and corner pile (C) from the results from two scenarios analysis. Figure 10 shows Axial loads plotted altogether for those 3 corresponding piles in the two scenarios. It appears that The raft affects the distribution of axial load on the top piles with pile (C) in the corner suffer the lowest axial load and the middle pile (B) suffers the highest axial load among others. This is reasonable since the surface area of 15 kPa will concentrate in the middle of the raft.

Overall, the groundwater extraction will increase the amount of drag load generated on all piles. The total drag load experienced by the pile C is about 190 kN without groundwater extraction and 210 kN with the commencement of groundwater extraction. Comparing interior-corner pile (A) and middle pile (B), the middle pile's axial force is about 10 percent higher than the interior-corner pile's for the first 10 m depth. Going deeper after -10 depth, the pile axial forces between two piles lies on the same axial forces level for both with and without groundwater extraction. Eventually, the two piles' axial loads reduced at depth -13.5 m, which means that positive skin friction is already developed.

From both scenarios, the pile C in the corner encounters the highest drag load among others. This corner pile and piles located on the perimeter will act as a shield to the other piles, and hence the pile A and B suffer lower drag load. The neutral point of pile C is located about depth -12 and the other piles' neutral point located about at depth -13.5. The pile in the corner suffers the highest rotation due to the drag load or raft surface load, this may be the reason why it has a higher neutral point among others. Comparing those values with the neutral point value obtained from the rule of thumb method $0.6 L_{pile}$ and $0.75 L_{pile}$, -12 and -13.5 are still within approximation value. Recall that Pile top-level is -1 and tip level is -18, the pile length is 17 m. Using the rule of thumb of $0.6 L_{pile}$ and $0.75 L_{pile}$ to calculate the neutral point, the piles' neutral points are 11.2 m (depth -12.2 m) and 12.75 m (depth -13.75 m), respectively. Using $0.6 L_{pile}$ is on the more optimistic side in this case, since $0.6 L_{pile}$ can only represent the neutral point for the corner pile (-12.2 m < -12 m). The $0.75 L_{pile}$ is considered the more reliable method to simplify the design

process to represent all piles, as the hand calculated value of -13.75 is comparable with -13.5 from the result of finite element analysis.

The increases in drag loads after the commencement of the groundwater extraction is related to the degree of mobilization of the skin friction. The axial loads distribution curve for each pile for both scenarios has a similar trend or shape. This means that the mobilized negative skin friction development is more or less have a similar value. The degree of mobilization issue is discussed in the next section.

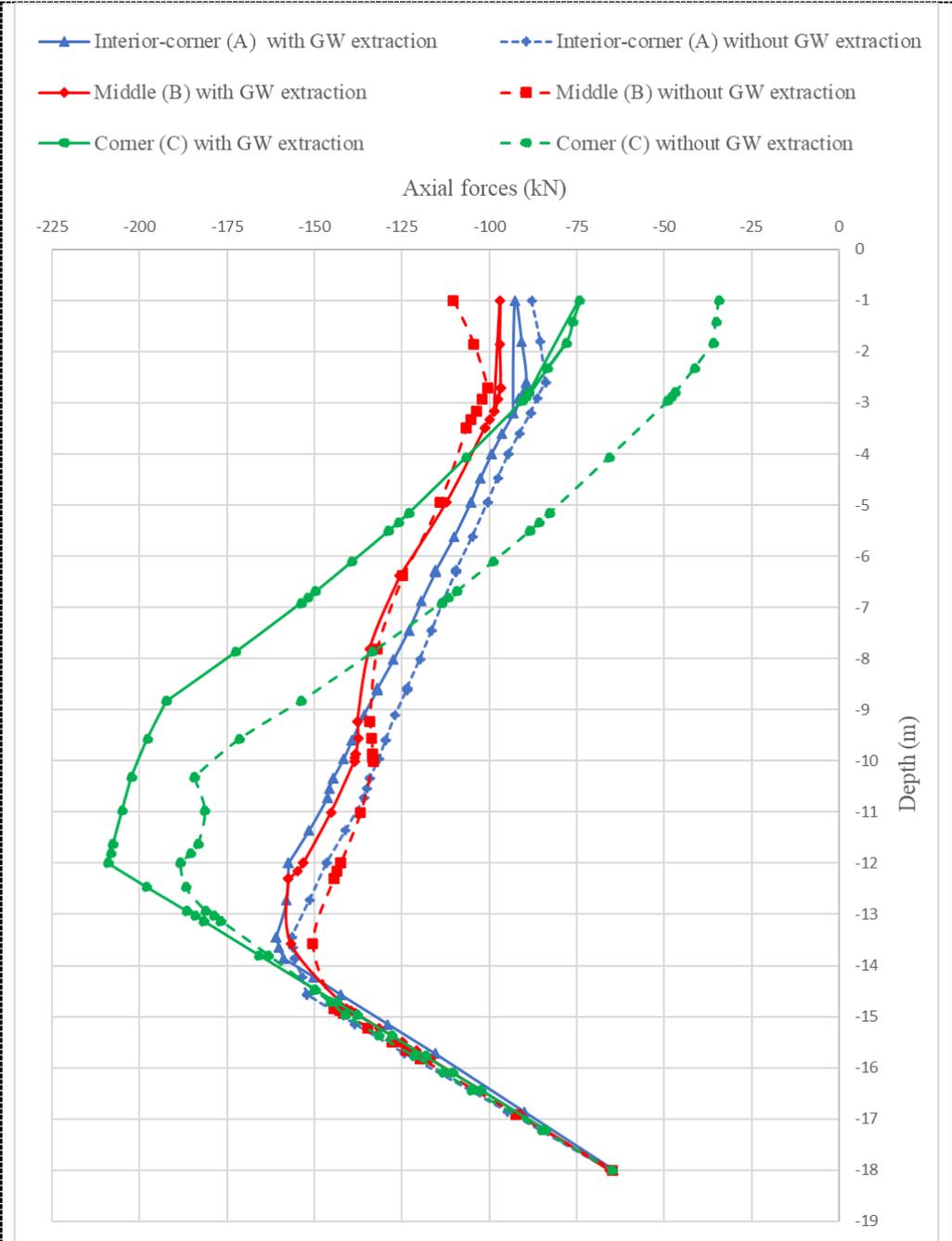


Figure 10. Distribution of axial forces over depth with and without groundwater extraction of three observed piles in 50 years.

4.4. Degree of mobilization between observed piles

In Plaxis, the analysis of axial load on piles can be broken down into a smaller fraction of skin friction mobilization. The positive or negative skin friction development can be obtained and plotted per meter run along the pile length as shown in figure 9. From the figure, each pile has the same trend and shape of skin friction mobilization between two scenarios. The maximum skin friction is limited to 25 kN/m. Corner pile (C) encounters overall higher axial loads, in the other words, it encounters the highest mobilized negative skin friction. The average mobilized skin friction for pile C is about 16 kN/m, with an average degree of mobilization (η) of 0.64 or 64 % (calculated from $16/25 \times 100\%$). The value complies well with the rule of thumb method in which for floating piles at least $0.67Q_{NSF}$ will be mobilized. Pile A encounters the lowest average mobilized negative skin friction of 5 kN/m with the average degree of mobilization of 0.2 or 20% calculated from $5/25 \times 100\%$. Pile B has a little bit higher degree mobilization than pile A, with an average mobilized negative skin friction of 7 kN/m and hence the average degree of mobilization of 0.28 or 28% calculated from $7/25 \times 100\%$. This means that the average degree of mobilization is getting higher on piles towards to outer corner or perimeter. Piles located on the perimeter will act as a shield for the inner piles resulting in a lower degree of negative skin friction mobilization for the shielded piles.

The mobilized degree of mobilization may be related to the spacing of piles and the type of piles that are used on the construction. Thus, the degree mobilization for the interior piles (Pile A and B) may not be used for different conditions. Simply taking all piles as $0.67Q_{NSF}$ will be much more reasonable as an act of a more conservative approach to simplify the design process.

Although in designing “floating” piles designer can assume that NSF will be $0.67Q_{NSF}$ for all piles, it is safer to assume that the mobilized NSF will have 100 percent mobilization unless a static pile loading test is conducted on-site for verification.

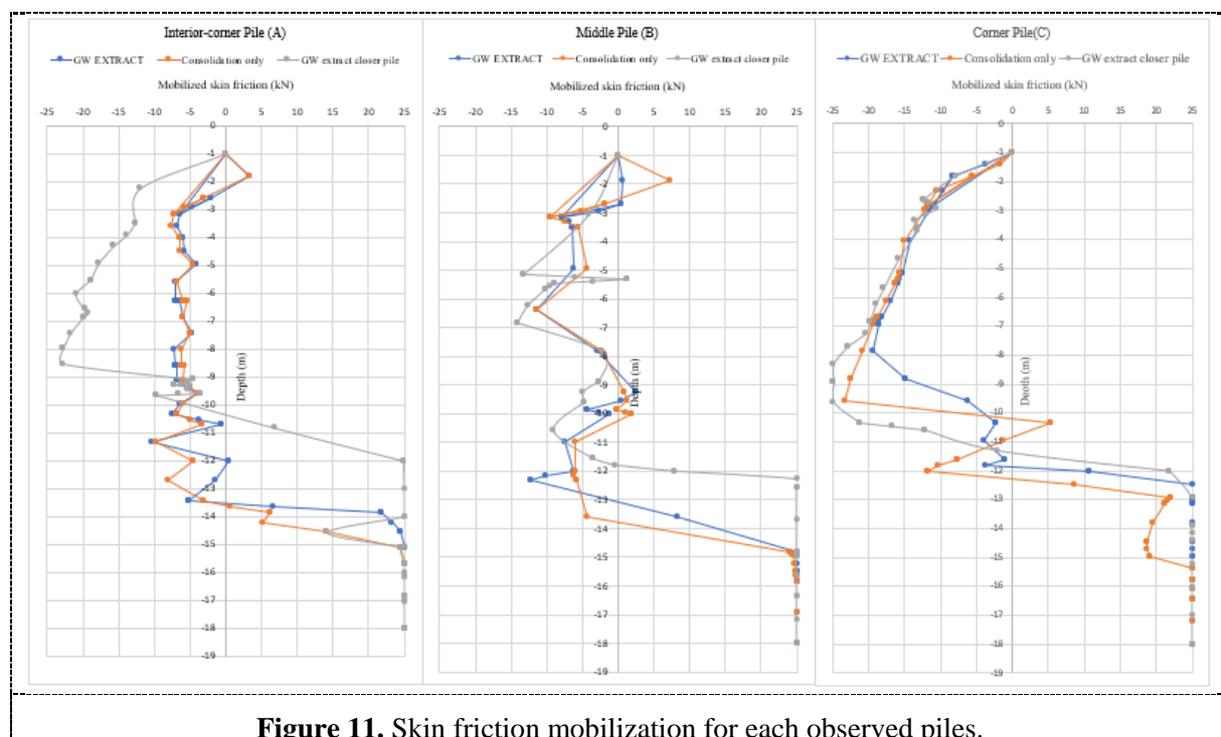


Figure 11. Skin friction mobilization for each observed piles.

The discussed results were modeled by using the corner pile (Pile C) horizontal distance about 20 m to the pump. This means that pile A is completely shielded by the piles located on the perimeter. Another

FEM was conducted to put the piles formation closer to the pump with the horizontal distance to pump about 5 m. With this situation, pile A became unshielded, and hence it experiences higher mobilized negative skin friction as added in figure 11. As pile A becomes unshielded, therefore the mobilized negative skin friction is apparent to be similar to Pile C. The other piles, Pile B and C have about the same degree of mobilization although the piles are closer to the pump. Given in figure 12 the settlement profile difference between original piles vs. piles with closer distance, the settlement occurred on the raft is still reduced by the installed piles but the settlement on the raft surface is higher. The closer the building location to the pump, the higher the building settlement.

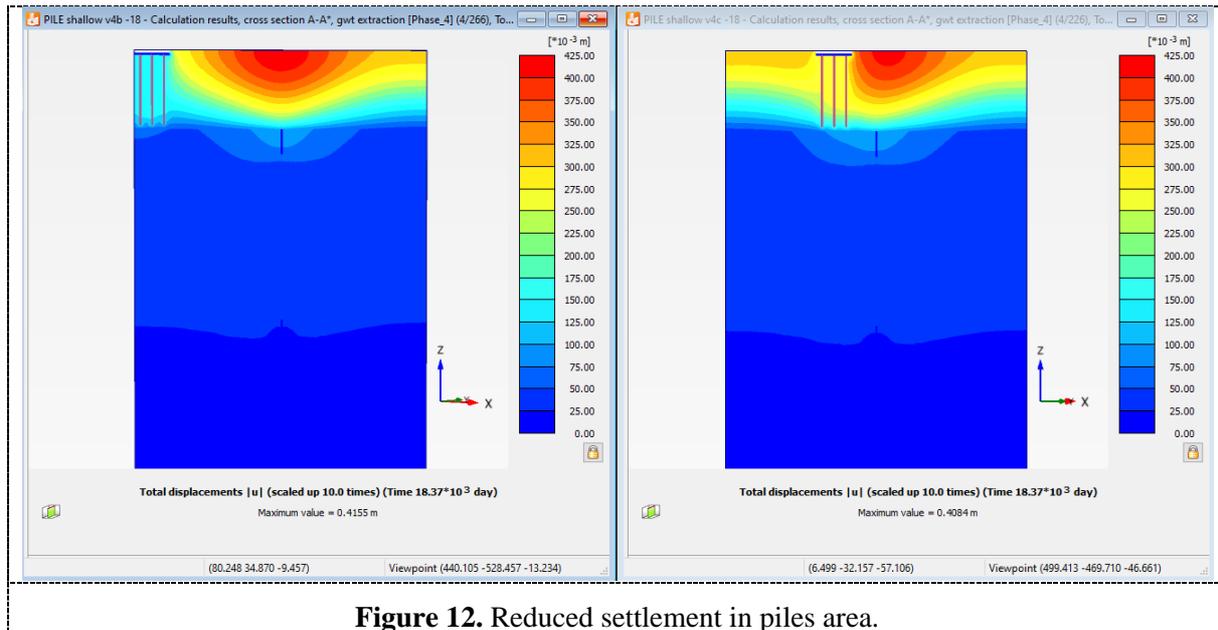


Figure 12. Reduced settlement in piles area.

5. Conclusion and recommendation

The Banger polder area has two aquifers that are still being used for water consumption by the local as of 2020. The groundwater extraction into those two aquifers has triggered land subsidence in the area. The effect of land subsidence induced by groundwater extraction in Banger was studied for long-term situations of 50 years, particularly about the effect of drag loads induced by settling soils surround the piled building.

A finite element model was executed to model and evaluate a foundation building with two scenarios analysis. The first scenario was to evaluate the NSF values of piles in 50 years without the groundwater extraction and the second scenario was to evaluate the NSF values of piles in 50 years with continuous groundwater extraction. The groundwater extraction was modeled as a water pump model by using software called Plaxis 3D 2020. The foundation type was floating piles underlying a concrete raft with 300 mm thickness. The pile used for analysis was steel pipe pile (SPP) type with the diameter and thickness of 610 mm and 3.5 mm respectively. The piles were modeled as embedded beams in Plaxis.

Three piles located on the corner (Pile C), middle (Pile B), and interior-corner (Pile A) were observed from the result of a finite element model. In 50 years with groundwater extraction, the settlement on the area is almost double the value from 0.24 m without water extraction to 0.42 m. The settlement amount may not be accurate in reality (e.g., the calculated settlement vs. direct land subsidence measurement) since the model is dedicated only to study the effect purely from the water extraction and natural subsidence of the area. The effect of actual landfilling (e.g., heightening of the land for housing and roads) was not taken into account in the model.

The pile on the outer corner (Pile C) experiences the highest mobilized NSF for both cases with and without groundwater extraction. Mobilized negative skin friction for pile in the outer corner is about 64 percent out of the total skin friction capacity while the middle and interior-corner experience less mobilization. Therefore, the pile located in the corner is the most critical pile to be concerned when designing piles foundation subjected with downdrag induced by the groundwater pumping. The middle and interior-corner piles experience less downdrag as the corner pile acts as a shield for piles located in the interior.

The neutral points of piles obtained from FEM were also compared with the rule of thumb method when designing piles subjected to NSF. The neutral point of floating piles obtained from FEM shows good agreements with $0.75 L_{pile}$ to simplify the design process.

This coupled flow-deformation finite element model was produced with a medium mesh system size. The finite element modeling result using Plaxis is very mesh-sensitive. The finer the mesh, the precise the analysis. Conducting such analysis with a very fine mesh system is recommended, although refining the meshing for analysis will cost time to finish the analysis. Modeling groundwater extraction with a pump produces the highest settlement magnitude only in the middle of the model. Lowering the water head from edge to edge in the model in a specific aquifer will have better insight to model total subsidence due to the compaction of the whole aquifer. However, doing that will significantly increase the time to run the model. Moreover, land subsidence is a world-wide geohazard problem that can cause issues to the building structures, and hence discussing and compiling geotechnical and structural failures of infrastructures caused by land subsidence can be very interesting and important for future research.

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