Efficiency Analysis of Foundation System (Combined Bored Pile and Raft Foundation) Building Structure on Silt Clay Soil

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Abstract

The increasing number of residents in South Tangerang has an impact on increasing the need for lower housing. The development of vertical housing with the market name of flats, apartments and is the most effective anticipatory solution to overcome land prices which result in market limitations, especially for the upper middle class. This 32-storey apartment project uses a combined foundation system between drill pile foundation & raft foundation. With the combination of these two very massive systems, of course, it will have a very expensive cost to implement and take a long time to complete. In order to avoid cost overruns, the foundation design must look at the possibilities. To determine the efficiency of the combined system foundation design between pile bored foundation & raft foundation, the researchers analyzed the value of the bearing capacity and also the settlement that occurred in the existing foundation using the Poulos method, the equivalent Raft method and the Vesic method. From the results of the study, it was found that the contribution of the pile foundation bearing capacity was 24.10%. the placement of the raft foundation is 75.90% and the settlement analysis using the Poulos 8.95cm method, the 12.41cm Equivalent Raft method and the Vesic 12.1cm method, these three results are close to the maximum settlement limit.

Keywords:

Apartment, Bored Piles, Raft Foundation, Poulos Method, Equivalent Raft Method and Vesic Method.

1. Introduction

South Tangerang City is one of the important satellite cities of the capital city of Jakarta. The large number of people who support the activities of the City of Jakarta then have a new impact on Tangerang Regency and South Tangerang City. Apart from being the city where the country's main airport stands and as an industrial area, Tangerang Raya is also known as a rapidly growing residential area. The increase in population has become a complex and difficult problem to solve, especially in urban areas, especially in big cities in Indonesia, resulting in the need for land to continue to increase Wahyudi Wahyudi, Irwan Irwan, (2017). The development of vertical housing under the market name of flats, apartments and condominiums is the most effective anticipatory solution to overcome the high price of land which results in limited market share, especially for the lower middle class. The Canary Apartment is an integrated residential complex. The development includes a mixed-use concept that includes residential units, garden houses, and offices.

The Canary Apartment is a 32-floor apartment project. The project is located in Tangerang, Banten which is included in the low earthquake zone and is built on silty to medium clay soil where the hard soil elevation (N-SPT 50) is at a depth of > 50 m. The foundation system used in this building is a combination of bored piles and raft foundations. Bore pile foundation with a depth of 32 m and a raft foundation with a thickness of 2 m above which also functions as a pilecap. Where the combination of bore pile and raft foundation is located in the tower area of The Canary Apartment. Thus, The Canary Apartment tower is supported by a bore pile of 157 points which is quite a lot plus a raft foundation with a thickness of 2 m as a pilecap evenly distributed throughout the tower area.

With the combination of two very massive foundation systems, this will certainly have an impact on a very expensive cost to implement and a long time to complete Ali & Al-Kodmany, (2012), In addition, the condition of the building structure in the form of a 32-storey dwelling with a regular floor plan configuration and not located in an earthquake-prone zone still allows for efficiency of the massive foundation system as long as the settlement value is relatively safe. The focus of the author will be to review the combined foundation system by carrying out design efficiency, especially reducing the thickness of the raft foundation, which is no longer as thick as 2.0m or the number of piles and the depth of the pile used is not as deep as 33m. The review is carried out based on structural drawings, soil data and the existing foundation design report.

Based on the above review, in writing this final project the author uses the title:

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"Analysis of the Efficiency of the Foundation System (Combined Bored Pile and Raft Foundation) Building Structures on silty clay soil (Case Study of 32 Floor Apartment Development Projects in South Tangerang)".

2. Methodology

The research method used in this final project is quantitative method, field data and study from several literature studies.

Figure 1. Flowchart
 Source : Processed Researcher

2.1. Object of Research

In this final project, the object of research is the 32-floor Canary Apartment Development Project in South Tangerang – Banten.

2.2. Method of Collecting Data

Soil parameter data which includes the Index Properties and Engineering Properties of the soil were obtained from field testing of 2 boring points and 6 sondir points at the project site and continued with laboratory testing where the results of the soil parameters were compiled in a soil investigation report for The Canary Apartment Development Project Susila, Endra, (2012).

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2.3. Soil Investigation Job

1. Sondir
2. Deep Drill
3. Standard Penetration Test (SPT)
4. Undisturbed soil sampling
5. Laboratory Testing

Soil samples that have been taken from the field are then tested in the laboratory with tests that are in accordance with the needs of foundation planning for the Apartment The Canary 2 project which will be located in BSD – South Tangerang, namely by determining the soil classification, its physical and technical properties. All tests are carried out according to ASTM testing standards.

Tests carried out include:

1. Determination of soil physical properties
2. Determination of water content: ASTM D 2216
3. Determination of Specific Gravity : ASTM D 854
4. Determination of Grain Size Distribution : ASTM D 422
5. Determination of Plastic and Liquid Limits : ASTM D 4318
6. Determination of soil engineering properties
7. Unconfined Test : ASTM D 2166
8. UU Triaxial Test : ASTM D 2850
9. CU Triaxial Test : ASTM D 4767
10. Consolidation Test : ASTM D 2435

2.4. Soil Condition in The Canary Apartment Project

The subsoil of the The Canary Apartment Project area was evaluated using the overall test results in the field with the location of the points as shown in the plan attached to this report and the overall results of the laboratory tests, which are described below.

Drilling results and sondir test results

Field testing at The Canary Apartment Project site in BSD, South Tangerang, only consisted of 2 drill data to a depth of about 50m and 6 sondir data. The ground level of the review area is based on both drill point data and the 6 sondir data, based on about 4.63m~6.75m above the road level and according to information it will be adjacent to the Parkland Avenue building, which was previously built.

During the soil investigation at the ground level elevation, the drill points BH01 and BH02 were +5,943m and 4,721m, respectively. From the two drill data, it is estimated that the stratification of the soil layer is relatively inconsistent, especially the presence of a dense silty clay layer and an interspersed layer of dense sand/sand which is found starting at a depth of 10m.

In general, the composition of the soil layer consists of a mixture of clay and silt and partly sandy to the end of drilling (50m) which varies in consistency with interspersed layers of dense sand/sand that are inconsistent in their presence. The silty clay layer around the top 10m is generally very soft to moderately stiff, partially stiff and very stiff with N-SPT values = 2-8 partially with N-SPT values = 9-19.

6 sondir test showed that the partially sandy silty clay layer around the top 10 m has a cone resistance value $q_c = 5 \text{ kg/cm}^2 \sim 25 \text{ kg/cm}^2$ with some reaching a conical resistance value, $q_c = 30 \text{ kg/cm}^2 \sim 65 \text{ kg/cm}^2$

The sondir test was stopped at a depth of about 8.8~12.8m, ie when the sondir cone reached the sand/sand soil layer, the first was reached with a cone resistance value, $q_c \geq 250 \text{ kg/cm}^2$. The thickness of this dense sand layer, which is inconsistent, as stated in the 1-1' cross section, cannot be accepted from the sondir test results. From the BH1 data, the silty clay layer from a depth of 16m to 32m was found to be generally stiff to very stiff with a value of N-SPT = 15-28 with some (at 22.5m) reaching N-SPT = 35 with a thickness of less than 1.5m. Meanwhile, based on BH2 data, the silty clay layer (partially sandy) at a depth of 16m~32m was found to be dense and very hard with N-SPT values >30 .

So this shows that in addition to the inconsistent thickness of the intercalated sand/sand layer, the gray silty clay layer at a depth of 16~32m is also found to be quite inconsistent. The cemented silty clay layer at a depth of more than 33m is estimated to be in a consistent state, namely moderately dense/hard with a value of N-SPT = 37 ≥ 50 , some of which are estimated to be interspersed with a medium to dense layer of sand/sandy. 2 drill data at the location of The Canary Apartment Project shows a relatively inconsistent soil layer. So that the soil layer between the two drill points cannot be calibrated like BH-01 or BH-02. So for further planning it is recommended to add a drilling test.

Based on the geological map sheet of Jakarta and the Thousand Islands the stratification of the soil layers at the project site can generally be grouped into 2 formations (units), namely:

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The alluvium/alluvial (Qav) fan formation consisting of a Pumice Tuff layer and an alternation between a Tuff Layer and a Sandy Tuff layer

The Tile Formation (Tpg) consists of layers of Tufaan clay and Tufaan Sandstone Lenses.

In general, by comparing the results of field tests and geological maps, the stratification of the soil layers at the location of The Canary Apartment Project can be explained as follows:

UPPER STRATUM (CH/MH)

The soil layers, which are grouped as Upper Stratum at this project site, consist of a mixture of clay and silt with a red to reddish-brown color which is generally very soft to medium in consistency with some stiff to very stiff with an N-SPT value = 2-19 and resistance cone, $q_c = 5 \text{ kg/cm}^2 - 65 \text{ kg/cm}^2$.

This upper stratum is thought to be a Pumice Tuff layer from the Alluvium Fan formation. This upper stratum is found to a depth of about 9~10m.

CENTRAL STRATUM (SH/MH/CL/SP)

The silty/sandy clay layers and alternating sand layers are found from about 10m to 21m, grouped as alternating tuff layers with sandy tuff from alluvium peeled formations in this discussion. The sondir test generally stops when the sondir cone reaches the silty clay layer or the first dense sand layer is reached. The first layer of hard soil reached at this project site is relatively varied in thickness where at the bot point location BH-01 it is found to be around 5m, while at point BH-02 it is about 1m (cross section 1-1').

The consistency of the silty clay layer at the bot point location BH-01 varied from stiff to very stiff with N-SPT value = 15-21. Meanwhile, at the drill point location BH-02, a very stiff to dense layer of silty clay was found alternating with layers of medium to dense sand with a value of N-SPT = $25 \geq 40$.

LOWER STRATUM (CH/MH/CL/SP/SC/SM)

The soil layers found at a depth of more than 21m below the ground level at the bot-points BH-01 and BH-02 until the end of the drilling, were classified as lower stratum. The lower stratum generally consists of a layer of silty clay (partially sandy) of varying consistency. Up to a depth of about 32m the consistency of the silty clay layer is between very stiff to dense with an N-SPT value of 19-35 in BH-01, while at the BH-02 location it is generally solid with an N-SPT value of 40. Starting from a depth of about 32m until the end of drilling (~50m), the silty clay layer was found to be relatively more consistent in its presence, namely with a value of N-SPT = $37 \geq 40$ with some (inconsistent) inserted a relatively less dense layer of silty clay.

The stratification of the soil layer at this location can be estimated according to the value of N-SPT and cone resistance.

2.5. Pile-raft and Lowering Foundation Design

1. Pile-raft Foundation Design with Poulos Method

Geotechnical Parameter Study

The first thing that must be done after all the load data is obtained is to estimate the capacity of the pile-raft foundation system against the structural loads. The capacity of the pile-raft foundation system against vertical loads is calculated by adding up the ultimate capacity of the raft components with the total capacity of all piles in the system. The values used to calculate the bearing capacity of the raft and pile components were obtained from the correlation made by Decourt, (1995). The correlation is made on the basis of the N-SPT value.

a. Ultimate bearing capacity of raft components

$$p_{ur} = K1 N_r$$

wherein:

p_{ur} = The ultimate bearing capacity of the raft components (kPa)

N_r = N-SPT averaged over a depth of 1.5 times the width of the raft component (without units)

$K1$ = correlation factor for raft components (without units)

b. Ultimate bearing capacity of pile components

1) Pile's ultimate friction resistance

$$f_s = 2,8 N_s + 10$$

wherein:

f_s = Pile's ultimate friction resistance (kPa)

N_s = N-SPT average along the pile (without units)

2) Pile's ultimate end resistance

$$f_b = K2 N_b$$

wherein:

f_b = pile ultimate end resistance (kPa)

N_b = N-SPT near the end of the pole (without units)

$K2$ = correlation factor for pile components (without units)

2. Equivalent Raft Method

The efficiency of the combined foundation system (piles & raft foundation) / piled raft system in The Canary Apartment project is designed based on the equivalent raft method. This method was developed by Poulos, (1989) & Tomlinson, (1994) where the pile foundation in the piled raft system is converted into a slab foundation which is at $2/3 L$ of the top of pile.

Figure2. Raft Equivalent Metode

3. Metode Vesic

In the calculation of the settlement of group piles are generally larger than single pile foundations, because of the influence of stress on a wider and deeper area. Using Vesic (1977) gives a simple formula as follows :

$$S_g = S \sqrt{\frac{B_g}{D}}$$

Where :

S_g = single pole settlement (m).

B_g = pile group width (m).

D = foundation dimensions (m).

3. Result and Discussion

3.1. Result

1. Project Structural Data and Existing Condition

The Canary Apartment project is a high-rise building project with 32 floors and 2 semi-basement floors located in South Tangerang – Banten. functioned as an apartment/residential.

a. Area Data, Building Functions.

- 1) Land Area : 2995,4 m²
- 2) Number of floors : 32 lantai, dengan 2 basement, 1 Mezanine dan 4 Lantai area komersil.
- 3) Building function
 - a. Built to meet residential needs in densely populated areas.
 - b. A total of 603 apartment units of various types and sizes.
 - c. All units are in a 25-story tower.
- a) Foundation Type : Combined Raft Foundation and Bore Pile
- b) BoredPile Depth : 35 m
- c) Diameter : 80 cm
- d) Raft Thickness : 2 m
- e) Material Quality : $F'_c = 30 \text{ Mpa}$
 $F_y = 400 \text{ Mpa}$

The Canary Apartment project was built on soft to medium clay soil where the hard soil layer with $N > 50$ has not been found until the final drilling depth at an elevation of 50 m. The superstructure of the building is a

reinforced concrete building structure, beam column frame and shearwall. The lower structure of the building is in the form of a combined foundation system between bored pile piles and raft foundations.

2. Contribution to the Bearing Capacity of Raft Foundation and Pile Foundation

Raft Foundation Bearing Capacity (Without Piles Involving)

Raft Foundation Data :

Raft Thickness (rb) = 2 m

Raft Thickness (Pw) = 71.999 ton

Raft Length (Lr) = 60 m

Raft Width (Br) = 35 m

Raft Area (Ar) = 60 × 35 = 2100 m²

Calculation of the carrying capacity of the raft using the Meyerhof method (general bearing capacity):

Meyerhof . bearing capacity factor:

$$F_{cs} = 1 + \frac{B}{L} \times \frac{N_q}{N_c} = 1 + \frac{35}{60} \times \frac{1}{5.14} = 1,112$$

$$F_{cd} = 1 + 0.4 \times \frac{D_f}{B} = 1 + 0.4 \times \frac{2}{35} = 1,022$$

$$F = F_{qs} = F_{qd} = F_{qi} = F_{ys} = F_{yd} = F_{yi} = 1$$

Then the bearing capacity of the raft foundation:

$$q_u = c \times N_c \times F_{cs} \times F_{cd} \times F_{ci} + \gamma \times D_f \times N_q \times F_{qs} \times F_{qd} \times F_{qi} + \frac{1}{2} \times \gamma \times B \times N_\gamma \times F_{ys} \times F_{yd} \times F_{yi}$$

$$q_u = 75 \times 5,14 \times 1,112 \times 1,022 \times 6,69 + 2 \times 1 \times 1 \times 1 \times 1 \times 1 + \frac{1}{2} \times 6,69 \times 35 \times 1 \times 1 \times 1 \times 1$$

$$q_u = 305.001 \text{ ton/m}^2$$

Then the ultimate bearing capacity of the raft foundation:

$$Q_u = q_u \times A_r$$

$$= 305.001 \times 2135$$

$$= 640502.1 \text{ ton}$$

a. Pile Foundation Bearing Capacity (Without Involving Raft)

Pile bearing capacity (single pile & group pile) is taken from the foundation report.

Data Pondasi Bored Pile :

Number of poles (n) = 157 tiang

Pole size = Ø80 cm

Pole depth = 35 m

Safety Factor (SF) = 2,5

Efficiency factor (eff) = 0,9

1) Single pile bearing capacity (*single pile*)

$$\text{Pile group clearance } (Q_{all(s)}) = 576 \text{ ton}$$

$$\begin{aligned} \text{Single pile ultimate bearing capacity } (Q_{u(s)}) &= Q_{all(s)} \times SF \\ &= 576 \times 2,5 \\ &= 1440 \text{ ton} \end{aligned}$$

2) Bearing capacity of pile group (*Group Pile*)

- When treated as a single pole

$$\begin{aligned} \text{Pile group clearance } (g) &= n \times (s) \times eff \\ &= 157 \times 576 \times 0,9 \\ &= 81388.8 \text{ ton} \end{aligned}$$

- When treated as a pile group

$$\text{Pile group clearance } (Q_{all(g)}) = 81388.8 \text{ ton}$$

$$\begin{aligned} \text{Pile group ultimate bearing capacity } (Q_{u(g)}) &= n \times (s) \times eff \\ &= 157 \times 1440 \times 0,9 \\ &= 203472 \text{ ton} \end{aligned}$$

b. Comparison of Raft and Pile Bearing Capacity

From the above calculations, the results of the ultimate bearing capacity of each foundation are as follows :

$$\begin{aligned} Q_u \text{ Raft} &= 640502.1 \text{ ton} \\ Q_u \text{ Pile} &= 203472 \text{ ton} \\ (all) \text{ Sum} &= 640502.1 + 203472 \end{aligned}$$

$$= 843974.1 \text{ ton} > Q_u \text{ beban struktur atas (71999 ton)}$$

- Comparison of the percentage bearing capacity of raft and pile foundations

$$Q_{uall} \text{ Raft} = \frac{Q_u}{SF} = \frac{640502.1}{2.5} = 256200.84 \text{ ton}$$

$$Q_{uall} \text{ Pile} = \frac{Q_u}{SF} = \frac{203472}{2.5} = 81388.8 \text{ ton}$$

$$Q_{uall} \text{ Total} = 256200.84 + 81388.8 \\ = 337589.64 \text{ ton}$$

Then the percentage of bearing capacity borne by each foundation is :

$$\begin{aligned} \text{Raft Foundation} &= \left(\frac{Q_{uall} \text{ Raft}}{Q_{uall} \text{ Total}} \right) \times 100 \\ &= \left(\frac{256200.84}{337589.64} \right) \times 100 \\ &= 75.9 \% \end{aligned}$$

$$\begin{aligned} \text{Pile Foundation} &= \left(\frac{Q_{uall} \text{ Pile}}{Q_{uall} \text{ Total}} \right) \times 100 \\ &= \left(\frac{81388.8}{337589.64} \right) \times 100 \\ &= 24.1 \% \end{aligned}$$

From the calculation results above, the percentage of the carrying capacity of the boredpile foundation is 24.1% while the percentage of the raft foundation bearing capacity is 75.9%. The contribution to the bearing capacity of the raft foundation is greater than that of the bored pile foundation. In other words, the raft foundation plays a greater role in bearing the load from the superstructure in The Canary Apartment project compared to the pile foundation.

3. Pile Foundation System Efficiency

The efficiency of the combined foundation system (pile and raft foundation) / piled raft system in The Canary Apartment project is designed based on the Poulos method and the equivalent raft method

a. Metode Poulos

The capacity of the pile-raft foundation system against vertical loads is calculated by adding up the ultimate capacity of the raft components with the total capacity of all piles in the system. The values used to calculate the bearing capacity of the raft and pile components were obtained from the correlation made by Decourt, (1995). The correlation is made on the basis of the value of N-SPT.

b. Poulos Method Calculation

The manual calculation of the pile-raft foundation using the Poulos method is as follows:

Soil Properties

$$C_u = 75 \text{ Kpa} = 0,699 \text{ ton/ft}^2$$

$$\phi_u = 0$$

$$E_u = 52000 \text{ Kpa} = 484,64 \text{ ton/ft}^2$$

$$E' = 46800 \text{ Kpa} = 436,176 \text{ ton/ft}^2$$

$$\nu' = 0,35$$

$$\nu_s = 0,5$$

Raft Carrying Capacity

$$\text{Raft Thickness (rb)} = 2 \text{ m}$$

$$\text{Structure Load (P}_w) = 131,057 \text{ ton}$$

$$\text{Raft Length (L}_r) = 61 \text{ m} = 200.08 \text{ ft}$$

$$\text{Raft Width (B}_r) = 35 \text{ m} = 114.83 \text{ ft}$$

Raft's Ultimate Carrying Capacity (q_u)

$$q_u = 5,69 \times c_u$$

$$q_u = 5,69 \times 0,699 = 3,9773 \text{ ton/ft}^2$$

$$P_u = B^2 \times q_u$$

$$P_u = B \times L \times q_u$$

$$P_u = 114.83 \times 200.08 \times 3,977$$

$$P_u = 91372.316 \text{ ton} = 913.723 \text{ MN}$$

- **Ultimate Bearing Capacity of Mast Components**

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- Mast Ultimate Friction Resistance
 - Pile length = 35 m
 - Pile Dimension = 0,8 m
 - Pile Surface Area (A_p) = $4 \times \pi \times r^2 = 20.096 \text{ cm}^2$
- Tahanan friksi ultimit tiang (f_s)
 - $f_s = 2,8 \times N_s + 10$

Tabel 1 Calculation of the ultimate frictional resistance of pile components

Layer Thickness	Ns	fs	As	Ps	Ps
(m)		(kpa)	(m)	(N)	(MN)
16	15	52	1,8	1497,6	1,4976
8	26	82,8	1,8	1192,32	1,19232
TOTAL Ps				2689,92	2,68992

- Pillar Ultimate End Resistance
 - $N_b = 26$
 - $K_2 = 100$
 - Pile's ultimate end resistance (f_b)
 - $f_b = K_2 \times N_b$
 - $f_b = 100 \times 26$
 - $f_b = 2600 \text{ Kpa}$
 - $P_b = f_b \times A_p$
 - $P_b = 2600 \times 0,2001$
 - $P_b = 520,26 \text{ Kpa} = 0,520 \text{ MN}$
 - $P_u = P_s + P_b$
 - $P_u = 2,69 + 0,52$
 - $P_u = 3,210 \text{ MN} = 321 \text{ ton}$

- **Pile Foundation's Ultimate Bearing Capacity**

$$P_u = P_{ur} + n_p \times (P_s + P_b)$$

$$P_{ur} = 913.723 \text{ MN}$$

$$P_s = 2,69 \text{ MN}$$

$$P_b = 0,520 \text{ MN}$$

- **Calculation of Foundation Stiffness**

$$c = \frac{L_r}{2} = \frac{61}{2} = 30.5$$

$$d = \frac{B_r}{2} = \frac{35}{2} = 17.5$$

$$\frac{d}{c} = \frac{17.5}{30.5} = 0.574$$

$$v = 0.2$$

1. **Rigidity of Assembled Components**

$$K_r = \frac{G_s}{(1 - v_s)} + \beta_z \sqrt{4cd}$$

The average soil shear modulus to the pile tip depth

$$G_s = \frac{E}{2(1 + \mu)}$$

Tabel 2 Shear modulus calculation

Layer	μ	E (Mpa)	G_s (Mpa)
layer I (CH/MH)	0,5 (UD)	52	17,33
layer II (CH/MH)	0,5 (UD)	52	17,33
G_s Avg			17,33

Coefficients based on raft dimensions, c and d (β_z) = 2,1

Tabel 3 Calculation of bearing capacity and settlement using the Poulos method

No of piles	Pu	Pu	Pu	Kekakuan Grup Tiang (Kp-sys)	Kpr	α	βp	P	Pp	Pr	Pup	P1	Settlement	Settlement	
	(MN)	(KN)	(ton)	(MN/m)				(MN)	(MN)	(MN)	(MN)	(MN)	CASE	(m)	(cm)
1	168	167528	16753	158	168	-0,33	1,49	236	350	-115	3	2	P>P1	0,27	27,48
4	177	177177	17718	1036	336	-0,47	1,90	236	447	-212	13	7	P>P1	0,28	27,69
9	193	193259	19326	1553	505	-0,85	6,87	236	1620	-1385	29	4	P>P1	0,27	26,80
16	216	215774	21577	2071	673	-4,41	-0,29	236	-69	305	51	175	P>P1	0,33	32,83
25	245	244722	24472	2589	841	1,40	0,42	236	98	137	80	193	P>P1	0,28	27,74
36	280	280103	28010	3107	1009	0,60	0,62	236	147	89	116	186	P>P1	0,24	24,01
49	322	321916	32192	3625	1177	0,38	0,72	236	170	65	158	218	P>P1	0,20	20,50
66	370	370163	37016	4142	1346	0,28	0,78	236	184	52	206	264	P<P1	0,14	13,66
81	425	424842	42484	4660	1514	0,22	0,82	236	193	43	261	319	P<P1	0,13	12,73
100	486	485954	48595	5178	1682	0,18	0,84	236	199	37	322	381	P<P1	0,12	11,84
121	553	553498	55350	5696	1850	0,16	0,86	236	204	32	389	450	P<P1	0,11	11,01
157	627	627476	62748	6214	2018	0,14	0,88	236	207	28	463	526	P<P1	0,10	10,27

c. Metode Raft Ekuivalen

The efficiency of the combined foundation system (piles & raft foundation) / piled raft system in The Canary Apartment project is designed based on the equivalent raft method. This method was developed by Poulos (1993) & Tomlinson (1994) where the pile foundation in the piled raft system is converted into a slab foundation which is at $2/3$ L of the top of pile..

1) Equivalent Raft calculation method by comparison 1:4

- Raft dimensions
 - Raft Length (L) = 61 m
 - Raft Width (B) = 35 m
- Dimensions of the raft on $\frac{2}{3}$ pile length
 - Pile Length = 35 m
 - $\frac{2}{3}$ Pile Length = 23.3 m
 - Equivalent Raft Length (L') = 60 m
 - Equivalent Raft Width (B') = 35 m
 - Equivalent Raft Area = 2100 m
 - Raft Type Weight = 24 KN/ m³
 - Raft Thickness = 2 m
 - q Raft = 60 KN/ m³

Figure 3. Pemodelan raft ekuivalen 1:4

Source : Processed Researcher

Calculation of settlement of the raft foundation system (pile-raft system) with the equivalent Raft method is as follows:

From the calculation results, the value of the decrease in each layer is as follows:

$$\begin{aligned} s_1 &= 5,413 \text{ cm} \\ s_2 &= 0,9265 \text{ cm} \\ s_3 &= 2,6276 \text{ cm} \end{aligned}$$

Then the total decrease value is:

$$\begin{aligned} \text{total} &= s_1 + s_2 + s_3 \\ &= 5,413 + 0,9265 + 2,6276 \\ &= 8,97 \text{ cm} \end{aligned}$$

2) Equivalent Raft calculation method by comparison 1:1

Raft dimensions

Raft Length (L) = 60 m

Raft Width (B) = 35 m

- Dimensions of the raft on $\frac{2}{3}$ pile length

Pile Length = 35 m

$\frac{2}{3}$ Pile Length = 23,3 m

Equivalent Raft Length (L') = 60 m

Equivalent Raft Width (B') = 35 m

Luas Raft Ekuivalen = 2100 m

Raft Type Weight = 24 KN/m3

Raft Thickness = 2 m

q Raft = 60 KN/m2

Figure 4. Pemodelan raft ekuivalen 1:1

Source : Processed Researcher

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Calculation of settlement (settlement) of the raft foundation system (pile-raft system) with the equivalent Raft method is as follows :

From the calculation results, the value of the decrease in each layer is as follows:

$$s_1 = 7,704 \text{ cm}$$

$$s_2 = 1,282 \text{ cm}$$

$$s_3 = 3,421 \text{ cm}$$

Then the total decrease value is:

$$s_{\text{total}} = s_1 + s_2 + s_3$$

$$= 7,704 + 1,282 + 3,421$$

$$= 12,41 \text{ cm}$$

d. Metode Vesic

1) Determining the Drop Along the Pile (S1) Based on the Boring Hole (BH-1), it is known that:

$$Q_p = 1.511.125 \text{ kg}$$

$$A_p = 0,5024 \text{ m}^2$$

$$Q_s = 288.955 \text{ kg}$$

$$E_p = 2625035395 \text{ kg/m}^2$$

$$\varepsilon = 0,5$$

$$L = 35 \text{ m}$$

Maka,

$$S_1 = \frac{(Q_p + \varepsilon \cdot Q_s) \cdot L}{A_p \cdot E_p}$$

$$S_1 = \frac{(1.511.125 + 0.5 \cdot 288.955) \cdot 35}{0.5024 \cdot 2625035395}$$

$$= 0.024 \text{ m} = 2.4 \text{ cm}$$

2) Determining Pile Depression Due to Load at the End of Pile (S2) Known :

$$C_p = 0,04$$

$$Q_p = 1.511.125 \text{ kg}$$

$$q_p = 1.925.000 \text{ kg/m}^2$$

$$D = 0.8 \text{ m}$$

Then,

$$S_2 = \frac{(C_p \cdot Q_p)}{D \cdot q_p}$$

$$S_2 = \frac{(0.04 \times 1511125)}{0.8 \times 1925000}$$

$$= 0.041 \text{ m} = 4.1 \text{ cm}$$

3) Determining Pile Lowering Due to Load Continued Along the Mast (S3) Is known:

$$Q_s = 288.955 \text{ kg}$$

$$D = 1 \text{ m}$$

$$p = 3,14 \text{ m}$$

$$E_s = 2.000.000 \text{ kg/m}^2$$

$$L = 35 \text{ m}$$

$$\mu = 0.4$$

$$I_{wp} = 2 + 0.35 \sqrt{\frac{L}{D}}$$

$$I_{wp} = 2 + 0.35 \sqrt{\frac{L}{D}}$$

Maka,

$$S_3 = \left(\frac{Q_s}{p \cdot L} \right) \frac{D}{E_s} \cdot (1 - \mu_s^2) \cdot I_{wp}$$

$$S_3 = \left(\frac{288955}{3.14 \times 35} \right) \frac{0.8}{200000} \cdot (1 - 0.4^2) \cdot 3,917$$

$$= 0.012$$

So the total drop of the pole (s) :

$$S = S_1 + S_2 + S_3$$

$$= 0,024 + 0,041 + 0,012 = 0,077 \text{ m}$$

4) Immediate Decline Group Pole Drop

In the calculation of the settlement of group piles are generally larger than single pile foundations, because of the influence of stress on a wider and deeper area. The settlement of pile foundations in cohesive soils is an

immediate settlement. The following is an example of calculating the settlement of a pile group with a diameter of 0.8m.

Is known :

$$S_g = 0,077 \text{ m} \quad B_g = 1.44 \text{ m} \quad D = 0,8 \text{ m}$$

Then,

$$S_g = S \sqrt{\frac{B_g}{D}}$$

$$S_g = 0.077 \sqrt{\frac{1.4}{0.8}} \\ = 0.121 \text{ m} = 12.1 \text{ cm}$$

3.2. Discussion

1. Percentage of Bearing Capacity

From the calculation results above, the percentage of pile foundation bearing capacity is 24.20% while the percentage of raft foundation bearing capacity is 75.80%. The contribution of the raft foundation bearing capacity is greater than that of the bored pile foundation. In other words, the raft foundation plays a greater role in bearing the load from the superstructure in The Canary Apartment project compared to the pile foundation.

2. Metode Poulos

Based on the results of calculations using the Poulos method, the settlement value of the existing foundation (number of piles: 157 piles) is 8.95 cm, which is smaller than the allowable settlement value of 15 cm. And it can be concluded that the foundation system can still be efficient by reducing the number of piles. The number of poles that can be used is 66 poles so that the maximum settlement value is obtained. The settlement value resulting from the efficiency calculation is 13.66 cm (less than 15 cm).

3. Metode Raft Ekuivalen

For the calculation of settlement (settlement) with the Raft Equivalent method is divided into 2, namely with a ratio of 1:4 and a ratio of 1:1. Based on the results of calculations using a 1:4 ratio, the decrease in value obtained is 8.97 cm, while by using a 1:1 ratio, the decline value obtained is 12.41 cm.

The value of the decrease in the results of the calculation of the Raft Equivalent method between calculations with a ratio of 1:4 with a calculation of 1:1 there is a difference in the results of the decrease. Where the calculation with a ratio of 1:1 gets a greater reduction than the calculation with a ratio of 1:4. This is because in the calculation with a ratio of 1:4 the distribution of the load distribution is wider so that the resulting decrease is smaller.

4. Metode Vesic

From the results of calculations using the Vesic method, the settlement value of the existing foundation (number of piles: 157 piles) is 12.1 cm smaller than the allowable settlement value of 15 cm. And it can be concluded that the foundation system can still be efficient but with very small efficiency because the decrease is almost close to the specified safe limit of 15cm (Badan Standarisasi Nasional., 2017).

5. Comparison of Poulos Method, Equivalent Raft Method & Vesic

Between the Poulos method, the equivalent raft method and the Vesic method, the resulting impairment values are different. Where the results of calculations using the Poulos method, the resulting decrease is smaller than the Raft Equivalent and Vesic methods. This is because the Poulos method does not take into account consolidation decline. While the equivalent raft method takes into account the consolidation calculations that occur.

Figure1. Flowchart

Source : Processed Researcher

By using the Poulos method it is still possible to perform efficiency because in the existing foundation design the Settlement value is still far from the safe limit standardized in Indonesia..

4. Conclusion

Based on the results of the analysis on the combined system of raft and bored pile foundations, the following conclusions are drawn:

1. From the results of the analysis, it is known that the contribution of the bearing capacity of the raft foundation is greater than that of the bored pile. The percentage of the raft foundation bearing capacity is 75.90%, while the bored pile percentage is only 24.10%. This result is close to the requirements of the combined system design of the raft foundation and bored pile set in Badan Standarisasi Nasional., (2017) with a combination of 75% and 25%.
2. The design of the existing foundation in The Canary Apartment project with 157 piles with a depth of 35m and a raft of 2 m has met the requirements for carrying capacity and settlement. 8.95 cm then the equivalent raft method using a ratio of 1:1 the settlement value obtained is 12.41 cm and the last Vesic method is the settlement value on the existing foundation of 12.1cm. This result is smaller and has met the requirements of the maximum allowable total reduction limit of 15 cm (Badan Standarisasi Nasional., 2017).
3. In this case, the foundation system is deemed sufficient for efficiency, because the results of the three settlement analysis methods are close to the limit of the maximum allowable settlement. Efficiency can be done based on the Poulos method, which is where the decrease is still quite far from the specified safe limit or less than the total decrease allowed by Badan Standarisasi Nasional., (2017) which is 15 cm. However, this needs to be studied further because the calculation using the Poulos method does not take into account consolidation settlement and must pay attention to the requirements of the percentage contribution of the combined system of bored piles and raft foundations which are in (Badan Standarisasi Nasional., 2017).

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