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BEARING CAPACITY ANALYSIS OF FLOATING FOUNDATION MODEL IN HOMOGENEOUS VERY SOFT CLAY

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Abstract

This study focused on the effect of trapped water on the bearing capacity of PVC pipe pile foundations. This research is divided into two models. The first model (pressure cap pipe pole) and the second model (open press pipe pole) each consist of four variations of PVC pipe diameters of 5.08 cm, 6.35 cm, 7.62 cm, and 10.16 cm (standard size PVC pipe diameter) with the same length of 30 cm. In the first type, all pipes are tightly closed at their upper ends. In the second type, all upper-end caps are given two holes, each with a diameter of 0.5 cm. Each pipe pile is alternately piled into soft soil with a moisture content of 98.8% is in a glass box measuring 120 cm x 20 cm x 60 cm. The test results of the load against decrease were analyzed using the Mazurkiwicks interpretation method. The bearing capacity of the end of the pole *(Q_p)* along with the air trapped in the pipe pile *(Q_A)* can increase the carrying capacity of important poles compared to the carrying capacity of the pole side *(Q_s)*. PVC pipe poles belong to the floating pile foundation group due to the influence of air trapped inside the pile.

Keywords:

Pipe pile foundation;
Very soft soil;
Ultimate carrying capacity;
Trapped air.

1 Introduction

The city of Padang, like many other cities in Indonesia, is experiencing a rapid increase in population. This growth has resulted in an increase in demand for infrastructure, including the construction of roads and settlements. In the development process, open land such as rice fields and fields are often used to meet the need for space, especially for new settlements. Unfortunately, the use of these open lands has an impact on the loss of productive land, which previously served as a source of agricultural products. These lands often have soils with problematic characteristics, such as soft loam and peat. These soils have low bearing capacity, high compressibility and weak shear strength resistance. When used as a location for infrastructure development, such as road and residential buildings, technical challenges arise in choosing the right foundation [1] [2] [3] [4] [5].

The foundation is an important element in building a structure, as it serves to channel the load from the building above it to a more stable layer of soil. In the context of soft loam and peat soils, choosing the right foundation is crucial to ensure the stability and safety of buildings. The foundation serves to channel the load from the structure above it to a stronger and more stable layer of soil. However, the selection of the foundation must be adjusted to the characteristics of the local soil to optimize the carrying capacity and stability of the structure. In this context, research on the use of PVC (Poly Vinyl Chloride) foundations becomes relevant. The use of PVC pipe poles as a foundation in soft soil for residential houses with relatively small loads is an interesting idea because lightweight and malleable PVC material can facilitate the foundation installation process. However, the use of PVC as a foundation in soft soil has not been widely studied, so this study aims to understand the characteristics and behaviour of the foundation in facing soft soil challenges [1] [2] [6] [7] [8] [9].

PVC foundations have the advantage of being lightweight, malleable, and fast to install. This study focuses on compressive and tensile axial load tests against two models of PVC pipe poles with certain diameter and length variations. However, several other types of pipe pile foundations do not use polymeric materials but still use pipe piles as their main element, such as steel piles that have high

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strength and withstand heavier loads, usually used for large structures, such as bridges, towers or tall buildings. So is the foundation of concrete piles, wooden piles, and drilled piles by the method of drilling in the ground. This type of foundation is said to be a conventional deep foundation. There are several formulations of problems in this study, including, the influence of the diameter of the PVC pipe pole on the bearing capacity of the floating foundation on soft soil with compressive and tensile tests in the laboratory [10], whether the air trapped in the pipe pile affects the bearing capacity of the pile.

2 Material and methods

The use of PVC pipes is the latest innovation for a foundation that is environmentally friendly, resistant to acidic water, and easy to obtain. The test was carried out on a laboratory scale at the Department of Civil Engineering, University of Andalas.



Fig. 1: Sample pipe pole diameters 5.08 cm, 6.35 cm, 7.62 cm and 10.16 cm.

Pipe pile testing materials and methods in Model 1 (pressure cap pipe pole) and Model 2 (open press pipe pole) in the laboratory where pipe pile testing on soft soil is carried out by involving various steps and procedures to evaluate its carrying capacity. The test was carried out on two pipe pile models, namely Model 1 (pressure cap pipe pole) and Model 2 (open press pipe pole), in the laboratory. The testing material used is PVC poles with diameters of 5.08 cm, 6.35 cm, 7.62 cm and 10.16 cm (standard size pipe pile PVC), with a pole length of 30 cm as seen in Fig. 1. One end of the pole is tightly closed using a pipe cap according to the size of the diameter of each pole.

In Fig. 2 and Fig. 3, the perspective shapes of Model 1 (pressure cap pipe pole) and Model 2 (open press pipe pole) are shown respectively.

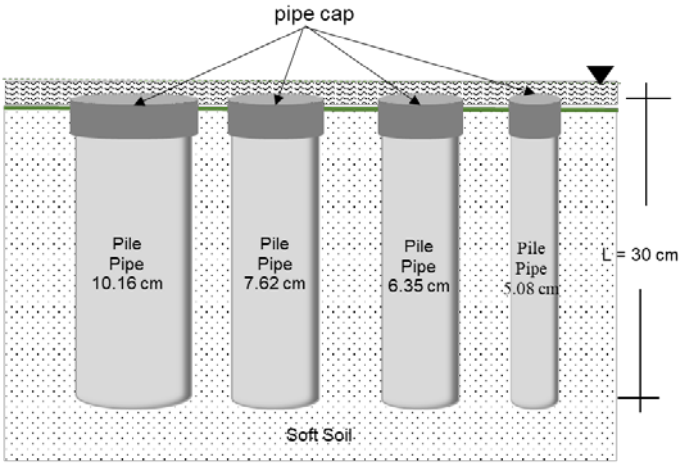


Fig. 2: Model 1 pipe pole perspective view.

Model 2 is a pipe pole that has an upper-end cap with an additional two holes in each, where each hole has a diameter of 0.5 cm.

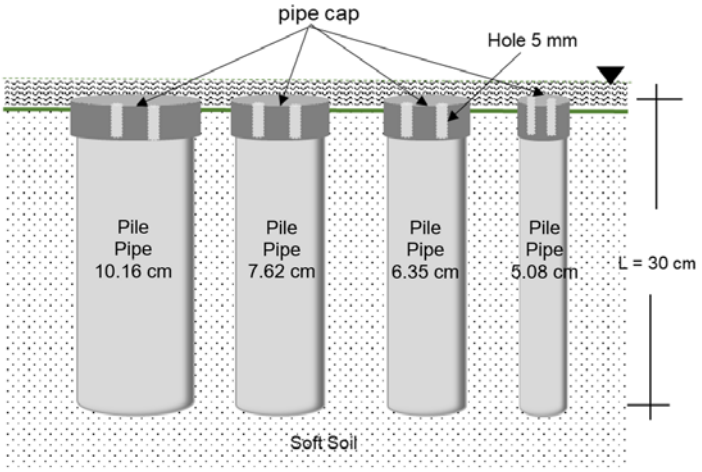


Fig. 3: Model 2 pipe pole perspective view.

The results of the soft soil properties testing are attached in Table 1 below.

Table 1: Soil Properties.

Parameters	Symbol	Value	Unit
Water Content	w	98.8	%
Volume Weight	γ	0.00163	kg/cm^3
Specific Gravity	Gs	2.5	-
UCST	q_u	0.202	kg/cm^2
Cohesion	c	0.101	kg/cm^2
Liquid Limit	LL	52.9	%

From the UCST (Undrained Compressive Strength Test) test results by ASTM D2166 standards, a value of 0.202 kg/cm^2 was obtained [11]. This value indicates that the soil is categorized as very soft soil. In addition, the soil moisture content after testing was 98.8%, which exceeded its liquid limit. After determining the value of soil properties, the soft soil in the glass box is compacted manually for 30 days before testing, as shown in Fig. 4.



Fig. 4: Compaction of soft soil in a glass box measuring 120 cm x 60 cm x 20 cm.

In addition, equipment for axial tests on pipe poles has also been prepared, including penetrometer sets, proofing rings and digital indicators, as shown in Fig. 5 below.

The test procedure is carried out on each pipe pile foundation model, especially on Model 1, by embedding them one by one into the soil in the glass box. The test starts from the smallest pipe pile diameters, which are 5.08 cm, 6.35 cm, 7.62 cm and 10.16 cm.



Fig. 5: Axial loading test equipment.

At each stage of the test, a load is applied and each load drop by 1 centimetre is recorded. Loading is stopped after the pipe pile is piled until the pipe head is parallel to the ground level or reaches a depth of 30 cm

After the loading test on each pole is completed, the observation continues by installing a dial gauge to determine the uplift value that occurs on each pipe pole. This happens because of the influence of soft soil samples. In addition, the height of the groundwater level also affects the phenomenon. Furthermore, because the lower end of the pole is exposed, there is an interaction between the ground around the pole and the air trying to exert pressure inside the airtight pipe pile.

If the descending load curve has been obtained from the pile load test, the Interpretation method can estimate the magnitude of the ultimate load of the pole. One of the methods of Mazurkiewicz (1972) assumes that the greatest resistance capacity (ultimate) will be obtained from intersecting loads, including loads that are in the direction of the pole axis for connected load with points from the position of the line to an angle of 45° on the axis load bordering the load. The procedure for determining the ultimate load using this method is as follows [12]:

1) Plot the load curve – decrease.
2) Select several drops and draw a vertical line that intersects the curve, Then draw a horizontal line from this intersection point on the curve until it intersects the load axis.
3) From the intersection of each curve, draw line 45° until It intersects the next load line.
4) This intersecting fall guess at line straight. The point which is in getting by Intersect from extension line at axis vertical (burden) be burden ultimate.

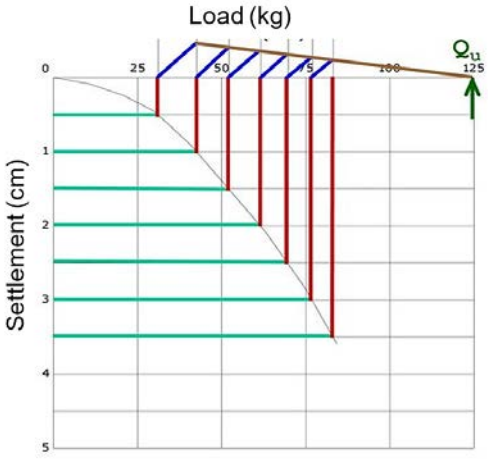


Fig. 6: Mazurkiwiecs method interpretation graph.

According to the rules in force, a foundation must have the ability to withstand the weight assigned to it. This foundation strength includes material and overall strength, including its interaction with the soil and other structures it supports [13].

In addition to the strength of the foundation material itself, the inner pile foundation must have the ability to interact with the ground so that it can support the load given. By convention, support on a pole foundation is the result of a combination of supports at the ends and along the sides. However, it should be noted that this support is highly dependent on the mechanisms used by the foundation to channel the load it bears into the soil. When facing a load that does not work in the direction of the longitudinal axis of the pole, it is necessary to analyze it by its method. However, if the load acts along the longitudinal axis of the pile, a general formula such as eq.1 applies to determine the bearing capacity of the pile foundation.

$$Q_u = Q_p + Q_s \quad (1)$$

Where:
Q_u - foundation load-bearing capacity,
Q_p - end bearing capacity (based) foundation,
Q_s - side bearing capacity (friction) along the foundation.

There are cases where only one aspect of the foundation provides a very dominant carrying capacity value. For example, when the foundation of the pile is fixed on soft soil until the end of the pile touches the harder ground, its carrying capacity depends mainly on the resistance at the end of the pole. In this case, the contribution of support from the foundation side is so small that it can be ignored. However, in other cases where the pile foundation is fixed on soft soil and the resistance at the end of the pile does not reach a hard soil depth compared to the resistance on the sides, this type of pile foundation is known as a floating pile [13].

Overall, determining the carrying capacity of both the ends and sides of the mast has been explained through several classical theories still used today to calculate the carrying capacity of conventional masts and floating poles. The determination of the carrying capacity at the end of the pole, Q_p, is measured in units of force and is written as follows [13] [14].

$$Q_p = A_p . q_p \quad (2)$$

Where:
A_p - cross-sectional area of the end of the mast,
q_P - the bearing capacity of the end of the mast interacts with the ground.

The carrying capacity of the side of the pile foundation, *Qs*, is a special aspect that is discussed especially for pile foundations that are on soft soil. Side resistance, or side carrying capacity, is the force that prevails along a pole and interacts with the surrounding ground and is written as follows [4]:

$$Q_s = A_s . q_s \quad (3)$$

with:

$$A_s = \Theta_i . L_i \quad (4)$$

where:
q_S - the value of the resistance of the side of the mast along L_i is a union-side resistance wide pole side,
Θ_i - pole circumference on hose L_i,
L_i - length of the mast section with circumference Θ_i.

3 Results and discussion

3.1 Model 1 pipe pile axial load test

The initial stage of testing is carried out on Model 1 (pressure cap pipe pole) for each pile diameter, namely 5.08 cm, 6.35 cm, 7.62 cm and 10.16 cm, with a pipe pile length of 30 cm. In this test, a load is placed on each pipe pile that has been erected in turn, and the test results are recorded. The test result data is then presented in the form of a curve that illustrates the decrease in load against a single pipe pole.

A view of the Model 1 single pipe pile testing perspective is presented in Fig. 7.

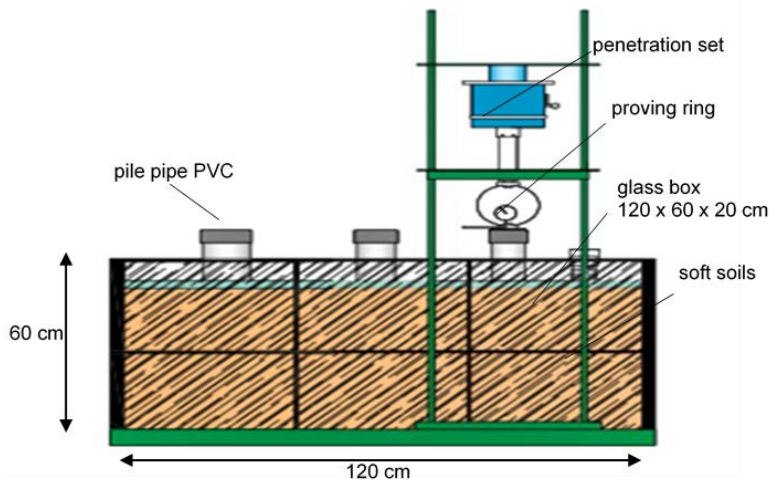
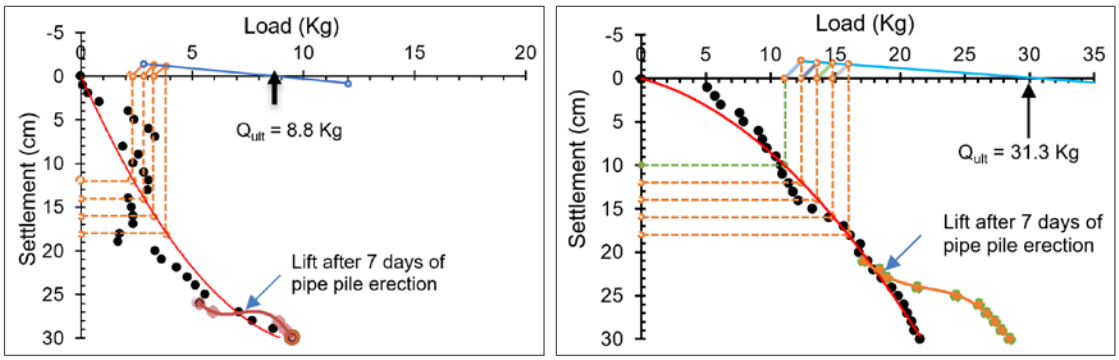


Fig. 7: Perspective view of axial loading test pipe pole.

The results of the axial loading test data processing are interpreted by the Mazurkiwiecs method for each variation in the diameter of the Model 1 pipe pile, as seen in Fig. 8, showing how to determine the ultimate bearing capacity of a pipe pile with a diameter of 5.08 cm based on the load - decrease curve.



a) b)

Fig. 8: Determination of the ultimate bearing capacity of pipe piles based on the load–settlement curve: a) Pipe pile diameter 5.08 cm; b) Pipe pile diameter 10.16 cm.

In Fig. 8a, the observed phenomenon occurs on a pipe pole with a diameter of 5.08 cm. Due to the small diameter of the pipe, the pipe pole becomes unstable in bearing the load during the beheading process. However, when the decrease reaches half of the mast length (1/2 L), there is an increase in the bearing capacity of the mast. Meanwhile, Fig. 8b illustrates that as the load increases, the stability of the mast increases as a function of the larger diameter size of the mast. It can be seen that after seven days of pipe pile erection, there is an uplift phenomenon on the pipe pole with a movement of 3 cm to 5 cm from ground level. This phenomenon occurs due to the presence of air trapped inside each closed pole. After reloading, the test results show that the resulting carrying capacity is greater than the initial carrying capacity in the previous test. Test results for Model 1 are presented in Table 2.

Table 2: Ultimate bearing capacity of Model 1 (pressure cap pipe pole).

Diameter pipe pole [cm]	**Carrying capacity *ultimate* Model 1 (Q_{ult}) [kg]**
5.08	8.8
6.35	13.5
7.62	19.2
10.16	31.3

In Table 2, there is an explanation that the largest ultimate carrying capacity occurs in the diameter of the 10.16 cm pipe pole, which is 31.3 Kg. The results of this test concluded that the larger

the diameter of the pipe pole, the more the ultimate carrying capacity, as can be seen in the graph listed in Fig 9.

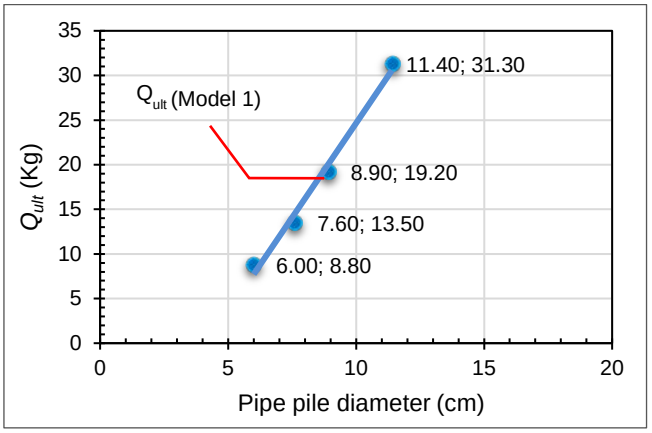
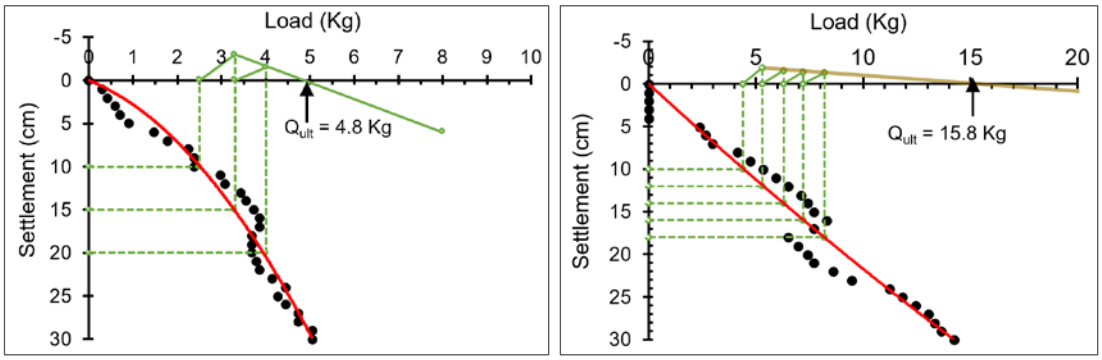


Fig. 9: Relationship curve between Q_{ult} Model 1 and pipe pile diameter.

From the data presented in Table 2 and the graph in Fig 9, it can be concluded that the size of the diameter of the pipe pole affects its carrying capacity. The larger the diameter of the pipe pole, the greater the ultimate carrying capacity that can be produced. This is important information in the design of the foundation because it allows to choice of the size of the pipe pile that corresponds to the required bearing capacity demands.

3.2 Pipe pile axial load test Model 2

Model 2 testing is performed by providing holes at the ends of pipe piles, and loads are applied to observe the drop as in previous tests on Model 1. The results of the axial test on the foundation of the Model 2 pipe pile show the carrying capacity produced, and these results are represented in graphic form.



a) b)

Fig. 10: Determination of the ultimate bearing capacity of pipe piles (Model 2) of the load–settlement curve: a) Pipe pile diameter 5.08 cm; b) Pipe pile diameter 10.16 cm.

In Fig. 10b, it is observed that the increase in load on the pipe pile drop is directly proportional to reaching half of the pile length (1/2 L). This phenomenon may be due to the larger diameter size of the pipe pole, which makes the pile more stable when subjected to load. In Model 2 testing, the influence of holes at the ends of pipe piles on carrying capacity can be observed. The graphs in Fig. 10a and Fig. 10b, visualize the carrying capacity levels generated by pipe piles at various loads and can provide important information about the performance and carrying capacity capabilities of Model 2.

Table 3, shows the full results of Model 2 testing with various pole diameters (in centimetre). Each row shows the load applied to the mast and the drop measured in cm on each such load. This data can provide detailed information about the carrying capacity and response of Model 2 pipeline piles to applied loads.

Table 3: Ultimate bearing capacity of Model 2 pipe piles (open press pipe pole).

Diameter pipe pole [cm]	Carrying capacity *ultimate* Model 2 Q_{ult} [kg]
5.08	4.7
6.35	6.8
7.62	10.0
10.16	15.8

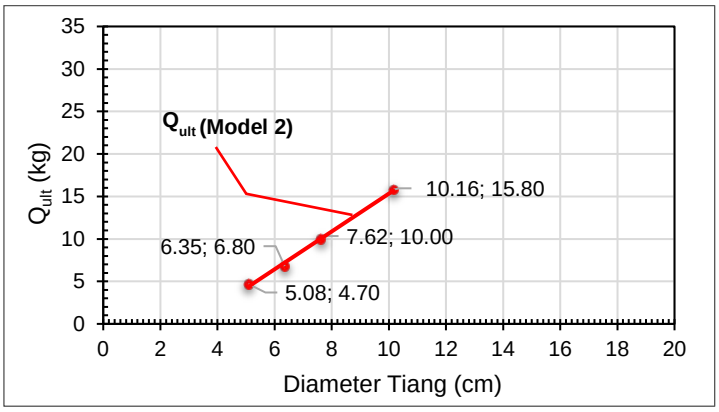


Fig. 11. Relationship curve between Q_{ult} (Model 2) and diameter pipe pile.

From Fig. 11, it can be explained that the increase in carrying capacity is directly proportional to the diameter of the pole used. In these two axial loading test models, it can be seen that the carrying capacity produced from closed pipe poles (Model 1) is greater than the bearing capacity value of Model 2 pipe poles which have holes at the ends.

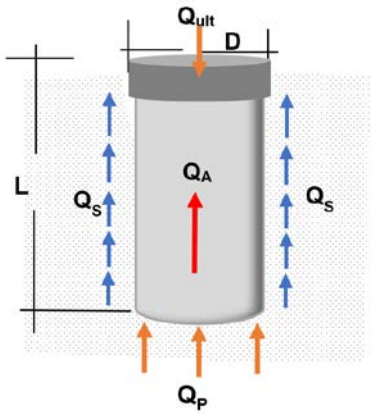


Fig. 12. Model 1 foundation (pressure cap pipe piles).

In the Model 1 pole (pressure cap pipe piles) Fig.12 explains that the hole in the pipe pole is filled with trapped air, so it is estimated to increase the end carrying capacity of the Model 1 pipe pole. It can be written like Eq. 5 with this article:

$$Q_{ult} = Q_P + Q_S + Q_A \quad (5)$$

where:
Q_{ult} - ultimate bearing capacity pipe piles close press,
Q_P - bearing capacity end of close pipe pole,
Q_S - power support side post pipe close,
Q_A - air carrying capacity.

While on the model 2 pipe pole, the air trapped in the pipe does not increase the carrying capacity of the pipe pole end, because the top of the pole head is given a hole, pay attention to the following Fig. 13.

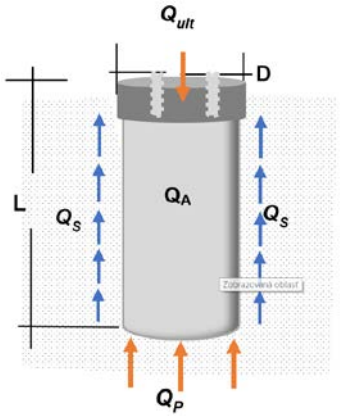


Fig. 13: Model 2 foundation (open press pipe piles).

$$Q_{ult} = Q_P + Q_S \quad (6)$$

Where:
Q_{ult} - Ultimate bearing capacity open press pipe pole,
Q_p - open pipe pile end bearing capacity,
Q_s - open pipe pile side bearing capacity.

Furthermore, the results of the carrying capacity simulation produced in each foundation model are shown in Fig. 12 and Fig. 13. The data obtained from these simulations provide a further overview of the bearing capacity differences between Model 1 and Model 2, as well as describe the characteristics of each foundation with different pile diameters. This simulation is an important tool in foundation analysis and design, as it makes it possible to select a model that corresponds to the required carrying capacity requirements. The Q_p (end bearing capacity) values of Model 1 and Model 2 pipe pile testing are presented in Table 4. and Fig. 14 below.

Table 4: End bearing capacity Q_P for Model 1 and Model 2 pipe piles.

Diameter pipe pole [cm]	End bearing capacity Q_P Model 1 [kg]	End bearing capacity Q_P Model 2 [kg]
5.08	4.63	2.2
6.35	7.45	3.0
7.62	11.18	3.8
10.16	17.76	6.3

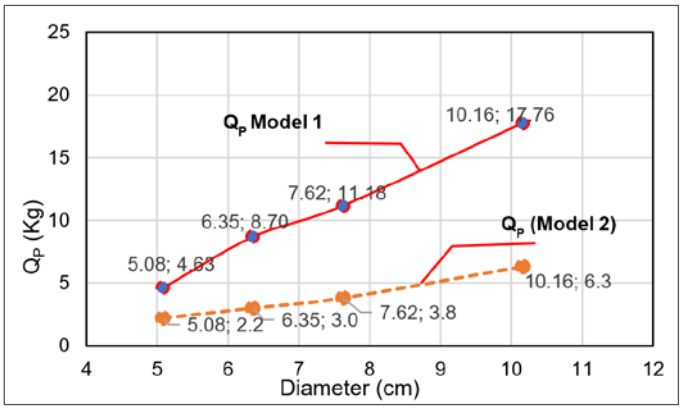


Fig. 14: Relationship of pipe pile end bearing capacity to diameter.

The results of these tests show the difference in end carrying capacity between Model 1 and Model 2, with Model 1 having a higher Q_p value compared to Model 2 at each pipe pile diameter.

3.3 Pipe pile tensile test

In addition, the Q_S value (side carrying capacity) obtained from tensile testing also provides important information about the ability of pipe piles to support loads from their sides. This information is very relevant in foundation analysis and design and can help in the selection of pipe pile models that match the required carrying capacity requirements.

Tensile tests are carried out on each pipe pile model to determine the value of the bearing capacity of the pipe pole side Q_s. Tests were carried out on pipe poles with various diameters, namely 5.08 cm, 6.35 cm, 7.62 cm and 10.16 cm, with the same pole length of L = 30 cm. A simulation of the tensile test on this pile pipe, showing how it responds when subjected to tensile forces, is shown in Fig. 15.

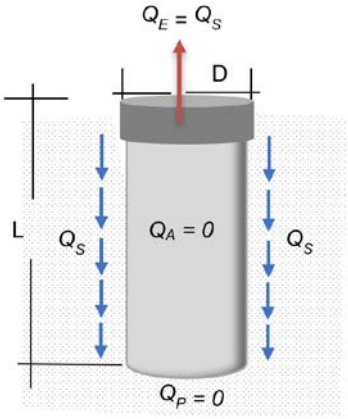


Fig. 15: Pipe pile tensile test simulation.

$$Q_E = Q_S \tag{7}$$

Where:
Q_E - ultimate tensile bearing capacity pipe piles open press,
Q_S - pipe pile side bearing capacity.

From the results of tensile testing on pipe poles, a value of tensile carrying capacity Q_E is obtained which is the same as the value of the carrying capacity of the *side* Q_S. That is, pipe piles show equal ability to withstand loads working from their sides and tensile loads. In addition, the bearing capacity value of the Q_P end obtained is *0*, indicating that the pipe pile in this tensile test does not experience an increase in bearing capacity at the end. Furthermore, the test results also show that no air is trapped inside the pipe pole, indicated by a Q_A value equal to *0*.

These results provide important information in the assessment of bearing capacity and pipe pile characteristics under tensile conditions. Thus, the data from these tests can be used in Foundation analysis and design to ensure adequate strength and stability of the structure.

The following are the results of tensile testing on pipe piles presented in Table 5 and Fig 16.

Table 5: Ultimate side bearing capacity of pipe piles Model 1 (pressure cap pipe piles) and Model 2 (open press pipe piles).

Diameter pipe pole [cm]	Qs side bearing capacity Model 1 [kg]	Qs side bearing capacity Model 2 [kg]
5.08	3.4	2.5
6.35	4.8	3.8
7.62	6.3	6.2
10.16	10.7	9.5

Table 5 displays the ultimate carrying capacity results obtained from tensile testing on Model 1(pressure cap pipe piles) and Model 2 (open press pipe piles). This result shows the maximum side bearing capacity value that a pipe pole can produce at each diameter.

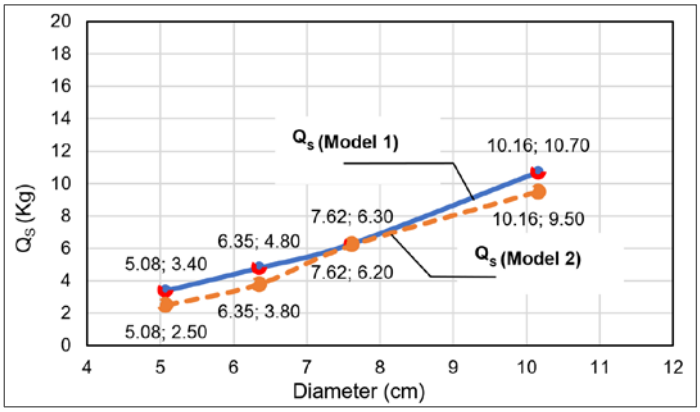


Fig. 16: Relationship of pipe pile side bearing capacity to diameter.

Fig. 16 is a curve depicting the ultimate bearing capacity of the sides (tensile) of Model 1 and Model 2 pipe piles at various diameters. This curve gives a visual idea of the difference in side carrying capacity (tensile) between the two pipe pile models, from Fig. 18, it can be seen that there is a difference in values between Q_E or Q_S for each pipe model, which ranges from 2% to 26%. In this study, the smallest Q_E value obtained from the Model 2 pipe pole was taken as a result of the tensile test *(Q_s).* In addition, the Q_A value is obtained through the carrying capacity analysis of both pipe pile models, as described in Fig. 17.

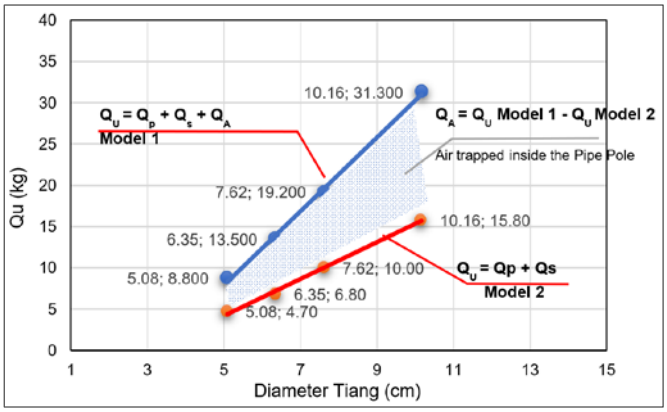


Fig.17: Determine the carrying capacity of the air inside the pipe pile (Q $_A$) from the relationship graph *(Q_u)* of the Model 1 pipe pile with the Model 2 pipe pile to the diameter.

Fig.17 is an overview of how the Q_E or Q_S carrying capacity value of the pipe pole is calculated and how the Q_A value is generated through carrying capacity analysis on both models of Pipe Piles. From the results of press and pull tests on PVC pipe poles, it can be seen that there is a significant difference in carrying capacity when compared to conventional pipe poles or floating raft piles that have been widely studied before [15] [16]. In this floating PVC pipe pole, the bearing capacity of the pole end (Q_p) is greater than the side resistance value (Q_S), both in Model 1 and Model 2 pipe piles.

This significant difference in carrying capacity indicates that PVC pipe poles have unique characteristics and are better at withstanding compressive and tensile loads. The greater bearing capacity at the end of the pile indicates that the PVC pipe pile can cope well with vertical loads, while its side resistance also contributes significantly to withstanding lateral loads or resistance to horizontal movement. The carrying capacity test results are plotted in a graph of the relationship of diameter to the ultimate bearing capacity of the mast, as shown in Fig. 18.

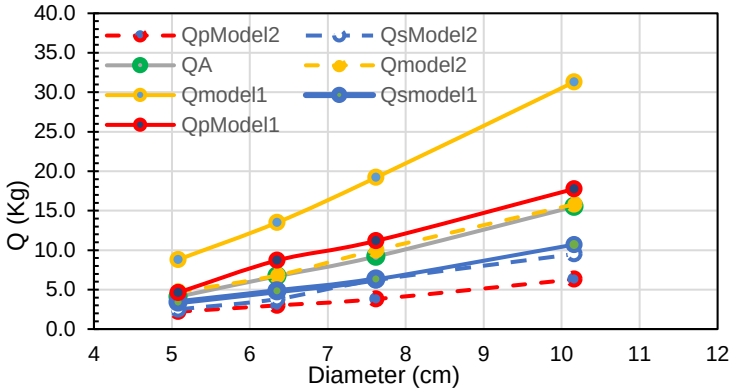


Fig. 18: Relationship curve between Q_{ult} pipe pile Model 1 and Model 2 to diameter pipe pile.

From the test results of both Model 1 and Model 2 pipe pile foundation models, there is a model 1 pipe pole (closed press pipe pole), the carrying capacity at the end of the pile (Q_p) and the carrying capacity by the surrounding soft soil Q_A (air trapped inside the pipe pile) work together to provide the carrying capacity of soft soil.

The air trapped inside the pipe pile *(Q_A)* which vacuums air and water can be analyzed mathematically simply from the combination of graphs in Fig.17. The equation is as follows:

$$Q_A = Q_u model\ 1\ -\ Q_u model\ 2 \tag{8}$$

where:
Q_A - air trapped inside pipe poles,
Q_u*model 1* - ultimate Carrying Capacity Model 1 (pressure cap pipe piles),
Q_u*model 2* - ultimate Carrying Capacity Model 2 (open press pipe piles).

Thus, the value of the carrying capacity of the air stored on the pole as shown in table 6 below.

Table 6: Air trapped inside pipe poles Model 1 pipe piles.

Diameter Pipe Pole [cm]	Q_A [N]
5.08	0.773
6.35	1,255
7.62	1,722
10.16	2,844

The carrying capacity *of* Q_A is generated by a very soft soil forming a fluid-like structure around the pipe pole which will provide lifting force on the pipe pole. To calculate the value of Q_A theoretically, we use Archimedes' law which requires information about the weight of the fluid displaced by the poles. The weight of this fluid depends on the volume of fluid displaced by the poles. In this case, the volume of fluid displaced is the volume of space filled by the poles when floating on soft ground.

Thus, the value of Q_A can theoretically be calculated by the following equation:

$$Q_A = \gamma_w\ x\ V_{pp}\ x\ g \tag{9}$$

where:
Q_A - air trapped inside pipe poles (N),
γ_w - unit weight of water (kg/cm^3),
V_{pp} - the volume of piled pipe pole,
g - acceleration of gravity (cm/s^2).

In the test results, it was found that the carrying capacity values of Q_A indicate the magnitude of the carrying capacity of the air trapped inside the floating pipe pile, which is generated by the soft soil around the pile at each diameter. The larger the diameter of the pipe pole, the greater the carrying capacity Q_A provided by the soft soil on the pole. This data has the potential to aid in the assessment of

the ability of floating pipe piles to provide support to soft soils and also plays an important role in ensuring the stability and safety of structures built on them.

4 Conclusion

From the results of these tests and analyses, it can be concluded PVC pipe poles show good performance in providing bearing capacity on soft soils. The bearing capacity of the mast end (Q_p) is greater than its side bearing capacity (Q_s) in Model 1 (pressure cap pipe pole) and Model 2 (open press pipe piles). In addition, the carrying capacity value Q_A generated from the fluid around the pile strengthens the overall carrying capacity of the pipe pile.

With these results, the use of PVC drift pipe piles can be considered an efficient and economical alternative in the construction of foundations and structures in soft soil. However, it should be noted that these test results are limited to laboratory conditions, so further research and field testing may be required to confirm the performance of PVC pipe piles in real applications. In addition, various other aspects such as cost, sustainability, and suitability to a particular project also need to be considered in choosing the right type of foundation.

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