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Prediction of Soil Bearing Capacity in the Masterplan Area of the Kalimantan Institute of Technology Based on Geographical Information System (GIS)

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ABSTRACT

Analysis of bearing capacity and soil type is a safety requirement before planning a building construction. CPT investigation only provides an overview at the point where the CPT was carried out. In contrast, data at other locations where soil investigations were not carried out is unknown what the value. This research provides a horizontal estimation of the bearing capacity and cone resistance values at a location regarding the sondir test points (CPT) that have been carried out. The soil bearing capacity and cone resistance mapping were carried out using three methods: Kriging, IDW and Spline with barriers. Analysis of bearing capacity was carried out by observing pile foundations with a diameter of 40 cm and a length of 11 m using the Trofimankove method in the master plan of Institut Teknologi Kalimantan (ITK). The analysis results show that the area's permit carrying capacity (Q_{all}) is 26,024 – 87,835 tons with hard soil types. The cone resistance mapping (q_c) results are 16,0804-259,54 kg/cm² with the soil consistency being stiff, very stiff, and hard. Results of comparison obtained from the mapping of cone resistance and carrying capacity of the three interpolation methods used, the values of the q_c and Q_{all} ranges closest to the sample data used are the IDW method. The result of this study can be used as an initial approach to planning foundations in areas where the bearing capacity value has not been sampled.

1. Introduction

Soil capacity in bearing construction loads is an important part that must be known in planning Building structures. The amount of the soil bearing capacity used to plan the foundation's diameter and depth that can carry the structure's load to be planned. Structural failure will occur if the bearing capacity of the soil cannot carry the planned structural load [2]. The ultimate bearing capacity is the maximum load presented in the form of a unit area load

where the load can still be accepted by the soil due to the working load without collapsing [1]. It is necessary to analyze the bearing capacity of the soil, which depends on the soil layer with different characteristics and soil types and has different soil bearing capacities[3].

The soil-bearing capacity analysis can be carried out using soil investigation data, one of which is the Sondir test or the Cone Penetration Test (CPT)[4]. CPT is very suitable for carrying out areas with a soft soil layer with a low bearing capacity[2]. CPT has been widely carried out in construction development in Indonesia because the process is easy to do, does not require a long time, and does not require many funds. The CPT investigation produces a cone resistance value which is used as input to the bearing capacity analysis. However, the values of the cone resistance and bearing capacity from the results of the CPT investigation only provide an overview at the point where the CPT was carried out. In contrast, data at other locations where soil investigations were not carried out or data between CPT points is unknown what the value of the bearing capacity and resistance of the cone is. It is necessary to deliver a method to predict the cone's bearing capacity and bearing capacity at that location.

The carrying capacity values can be predicted using ArcGIS interpolation from existing data. There are several interpolation methods in interpolating data using ArcGis, one of which is the Kriging Method [5]. The Kriging method is one of the interpolation methods used to assess Obtaining a representative value in the unsampled region based on the value at the sampled points using a semivariogram [6][7]. The types of the Kriging method is the Ordinary Kriging and spherical model [8][9]. Ordinary Kriging and spherical models will produce a more logical range value with better visual mapping at the closest distance than the farther distance [10]. Hidayat (2020) mapped the bearing capacity of shallow foundation soils using the Kriging method from CPT data using the Schermentmann method (1978). The Kriging method can be used in areas with low-density values at the sample points and homogeneous conditions[14].

The IDW method estimates the value in the unsampled region based on the value in the sampled region using a simple mathematical model by considering the distance to the surrounding points[11]. In this method, the visual mapping and the resulting range value are influenced by the power value, and the method for determining the area contained. The power value is a parameter that affects the results of the range of values to be interpolated and can be inputted with positive numbers. [12]. The interpolation results will form a pattern depending on how far the range can be interpolated at each data sample point so that there is a more extensive distribution pattern, and some have a smaller size[13]. Pratiwi (2021) mapped soil consistency from CPT data using the IDW method. Meanwhile, the IDW method is used for Prediction of Soil Bearing Capacity in the Masterplan Area of the Kalimantan Institute of Technology Based on Geographical Information System (GIS)

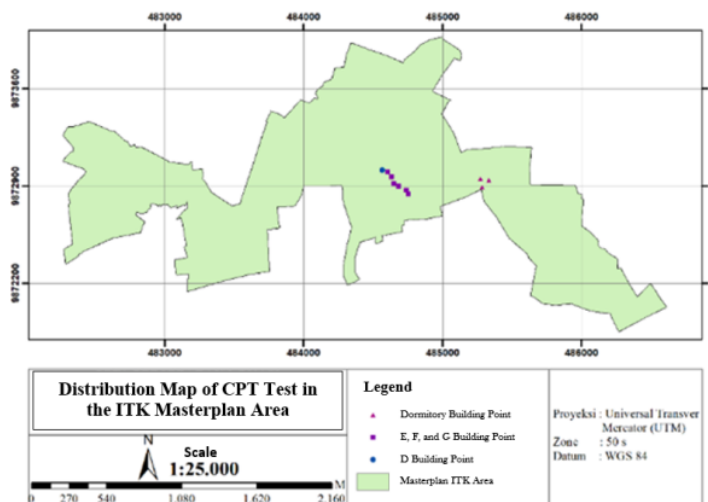
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areas that use high-density data samples so that the interpolation results will be closer to the close sample data [6]. Unfortunately, previous studies have not carried out a comparison of methods that are closest to field data. The Spline with Barriers method obtains smoother results with logical values and wider distribution [17]. The analysis aims to determine the distribution of bearing capacity and cone resistance in the ITK masterplan area, especially in areas that have not been sampled in the form of a map.

From the map, the distribution of the bearing capacity of the soil on the ITK Campus will be obtained. The soil bearing capacity and cone resistance mapping were carried out using three methods: Kriging, IDW, and Spline with barriers. From this map, it will be known how the distribution of bearing capacity and cone resistance distribution in ITK, soil consistency and which method is most appropriate in predicting the bearing capacity and cone resistance values based on actual data. This research is expected to be a reference material for related parties to assist in planning an infrastructure with a better level of security in the initial planning process.

2. Research Method

The analysis was carried out from the CPT test data that had been carried out in the ITK masterplan area, according to Figure 1 below. The CPT tests that have been carried out are scattered in buildings D, E, F, G, and dormitory buildings in the ITK masterplan area.



Source: ITK Planning Subdivision (2020).

Figure 1. Distribution Map of CPT Test in the ITK Masterplan Area.

2.1 Cone Penetration Test

The value of q_c is obtained from the results of direct CPT testing. Soil consistency describes the soil's resistance to deformation due to receiving pressure or other forces, such as loads, that can affect the shape of the soil as a form of adhesion and cohesion forces [22]. Good soil consistency has a low level of adhesion and is easy to cultivate [23]. Soil consistency can be determined by considering the cone resistance value (q_c) from the CPT test results shown in Table 1.

Table 1. The Relationship of Soil Consistency to Conus's Resistance Value.

| Soil Consistency | Field Identification | Cone resistance value (q_c) (kg/cm^2) | Undrained Cohesion (T/m^2) |
|------------------|--|--|---------------------------------------|
| Very Soft | It can be squeezed a few inches easily with a fist, push | <2,50 | <1,25 |
| Soft | Quickly pressed a few inches with thumb | 2,50 – 5,0 | 1,25 – 2,50 |
| Medium Soft | Can be pressed a few inches with the thumb relatively easily | 5,0 – 10,0 | 2,50 – 5,0 |
| Stiff | Can be pressed a few inches with the thumb relatively easily | 10,0 – 20,0 | 5,0 – 10,0 |
| Very Stiff | Easy to slice with thumb but requires much force to press | 20,0 – 40,0 | 10,0 – 20,0 |
| Hard | Difficult to slice with the thumb | >40,0 | >20,0 |

Source: Bagemann (1965) [24][25].

2.2 Bearing Capacity

Bearing capacity analysis was carried out using the Trofimankove method is closest to the results of the PDA test using CPT data [18]. The allowable bearing capacity is the maximum load presented in the form of a unit load that is permitted to be imposed on the ground provided that the foundation planning conditions have been met, namely the safety factor and tolerance for foundation settlement which are still within safe limits[19],[20]. The soil bearing capacity analysis was carried out by observing the foundation with a diameter of 40 m and a length of 11 meters according to the foundation planning data at the ITK Integrated Building.

$$Q_{all} = \frac{(K_b \times q_c \times A) + \left(\left(\frac{JHP}{D}\right) \times Q\right)}{SF}$$

Where

K_b = resistance of the pile end resistance factor of 0,75,

q_c = cone resistance (kg/cm^2), A = Base cross-sectional area of the pile foundation (cm^2),

JHP = Total Adhesive Resistance (kg/cm),

D = Foundation cross-sectional coefficient pile of 1,5,

Q = Perimeter of the pile foundation (cm),

SF = Safety Factor of 3.

The ultimate bearing capacity value in this research can be divided into four classes which can be seen in **Table 2**.

Table 2. Ultimate Soil Bearing Capacity Classification[19]

| Class | Description | Ultimate Bearing Capacity (kg/cm ²) | Ultimate Bearing Capacity using 40 cm Foundation (Tons) |
|-------|-------------|---|---|
| I | Very Good | >120 | >150.72 |
| II | good | 81 – 120 | 101.74 – 150.72 |
| III | Fair | 41 – 80 | 51.5 – 100.48 |
| IV | Poor | 0 – 40 | 0 – 50.24 |

Source: Gul and Ceylanoglu (2013) [12].

The relationship between the value of the allowable bearing capacity and the soil type on the foundation can be classified into four types of foundation soil which can be seen in **Table 3**.

Table 3. Allowable Soil Bearing Capacity Classification.

| Soil Foundation Type | Allowable Bearing Capacity (Kg/cm ²) | Ultimate Bearing Capacity using 40 cm Foundation (Tons) |
|----------------------|--|---|
| Hard | >5 | >6.28 |
| Medium | 2 – 5 | 2.51 – 6.28 |
| Soft | 0.5 – 2 | 0.63 – 2.51 |
| Very soft | 0 – 0.5 | 0 – 0.63 |

Source: PPIUG (1983)[21].

2.3 Distribution Map

The values of bearing capacity and cone resistance from existing CPT points are input data in ArcGis which will be interpolated with the Kriging, IDW and Spline with Barriers methods so that the values of bearing capacity and cone resistance are obtained in the entire study area.

a. Kringing Method

In the Kringing method, there are two stages of interpolation. First, creating a variogram function to estimate relatedness values can be called auto-spatial correlation, depending on the model or type used. The type used in the analysis are spherical and ordinary Kringing types. this type is more suitable for use because the range value from the interpolation results is very similar to the range value in the data sample used [6]. After determining the type, it can then predict the value to be interpolated in areas that have not been sampled and whose value is unknown. This method uses a mathematical model equation to be able to describe

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semi variance. The parameters of the tools that influence the cone resistance analysis are the type and number of samples used. In this study, the number of data samples used for interpolation was ten.

b. Inverse Distance Weighting (IDW)

One of the interpolation analysis tools found in the IDW method is inputting the power value parameter. The input power value is used to determine the importance of the data sample value in the interpolation calculation to be carried out. The power parameter value that is often used in analyzing interpolation is 2. This power value will have a more significant effect on sample points that are closer to each other so that it will produce a range value that is close to the sample data value and will have a negligible effect with increasing distance or on sample points that are far apart so that they produce a range value that differs significantly from the value of the sample data used.

The difference in the interpolation results produced by the IDW method can be caused by the input parameters, namely the power parameter, the type parameter, and the number of samples used. In this study, the IDW method uses a variable search radius type where this type will produce a varying radius for each interpolation. It depends on how far the sample point is looking for cells or areas around it, so some polygons resulting from the mapping will be more prominent, and some other polygons will be smaller depending on the density of the points around the cell or area interpolated [26].

c. The Spline With Barriers

The interpolation results produced by the spline with barriers method have differences in visual mapping and the results of the interpolation range obtained. The difference is influenced by the tool's parameters, namely the smooth parameter, the limiting data parameter, and the parameter of the number of data samples used. In the analysis of cone resistance mapping using the Spline with Barriers method, the smooth parameter used is 1. The smooth value contained in this method is only limited to a value of 0 or 1, and this study does not compare the smooth value parameter. Therefore, this study uses a value of 1 as a smooth parameter because the value of the cone resistance range will be closer to the value in the data sample when compared to using a smooth value of 0.

3. Result and Discussion

3.1 Cone Penetration Test (CPT)

Based on the results of the CPT test, the value of q_c at the reviewed foundation depth, which is 11 m, has a difference in each of the data sample points used.

Table 4. Cone Penetration Test Result

| No | Location | Station Mark | Depth (m) | q_c (kg/cm ²) | D = 40 cm Q_{all} (tons) |
|----|----------------------|--------------|-----------|-----------------------------|-------------------------------|
| 1 | C and D Building | S.01-D | 11 | 28,32 | 29,00 |
| | | S.01-E | 11 | 207,32 | 71,10 |
| | | S.02-E | 11 | 202,27 | 71,42 |
| 2 | E, F, and G Building | S.03-F | 11 | 257,89 | 86,94 |
| | | S.04-F | 11 | 252,83 | 86,09 |
| | | S.05-G | 11 | 252,83 | 87,77 |
| | | S.06-G | 11 | 252,83 | 87,44 |
| | | S.01-US | 11 | 197,77 | 68,75 |
| 3 | Dormitory Building | S.02-US | 11 | 207,66 | 77,48 |
| | | S.03-US | 11 | 202,72 | 76,81 |

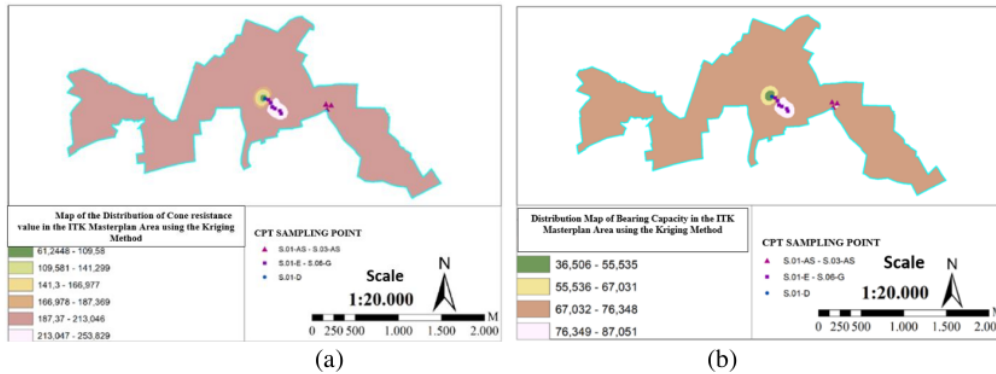
Source: Analysis

In **Table 4**, the analysis results show that the q_c value is 28,32 – 252,83 kg/cm² with a very stiff to hard soil consistency. While the value of Q_{all} is 29-87,77 tons which indicating the existence of hard soil.

3.2 Distribution Map

3.2.1 Kriging Method

Based on the mapping of the cone values obtained from CPT testing in the field, an analysis of Kriging spatial data. The mapping results have a visualization of the interpolation results using different colors produced. The results obtained are uniform in the area, which is far from the sample point used. The resulting color differences have different cone boundary values (q_c) based on the input q_c values. The resulting difference is influenced by the Kriging method's characteristics and the tool's input parameters.



Source: Mapping Analysis of Conus Resistance.

Figure 2. (a) Map of the Distribution of Cone resistance value in the ITK Masterplan Area using the Kriging Method (b) Distribution Map of Bearing Capacity in the ITK Masterplan Area using the Kriging Method

Figure 2 (a) shows that the ITK masterplan area has a hard soil consistency with a q_c value of around 61,2448 – 253,829 kg/cm². in the Kriging method, circular polygons tend to be centered around the area around the sample points used and have a radius that is not wide. From the interpolation results in the form of 2 circular polygons that are seen circling the data samples of Buildings D, E, F, and G, which have minimum and maximum values. The circular polygons generated from the mapping are not widely and evenly distributed. The maximum value of cone resistance from the interpolation range is 253,829 kg/cm² while the cone resistance value in the data sample is 257,89 kg/cm². The difference in values does not indicate that the interpolation range value is close to the maximum value of the cone resistance in the data sample, so the Kriging method with the spherical type can be used to interpolate the cone resistance value in the ITK master plan area.

The bearing capacity using the Kriging method, it produces a visual mapping almost similar to mapping the cone resistance with the Kriging method. The effect of the analysis carried out is the same. The value of the bearing capacity range generated in this analysis has a maximum value of about 87,051 tons and a minimum value of about 36,506 tons, while the minimum and maximum values in the data samples used are about 29 tons and 87,77 Tons. The maximum value generated in the interpolation analysis has the same value. Meanwhile, the minimum value generated by the interpolation analysis has a difference of about 7,506 Tons, which is greater than the minimum value in the sample data. By having the same value and not much difference in values, Figure 2b show that the ITK masterplan area has hard soil on the foundation with a Q_{all} value of around 36,506 – 87,051 Tons

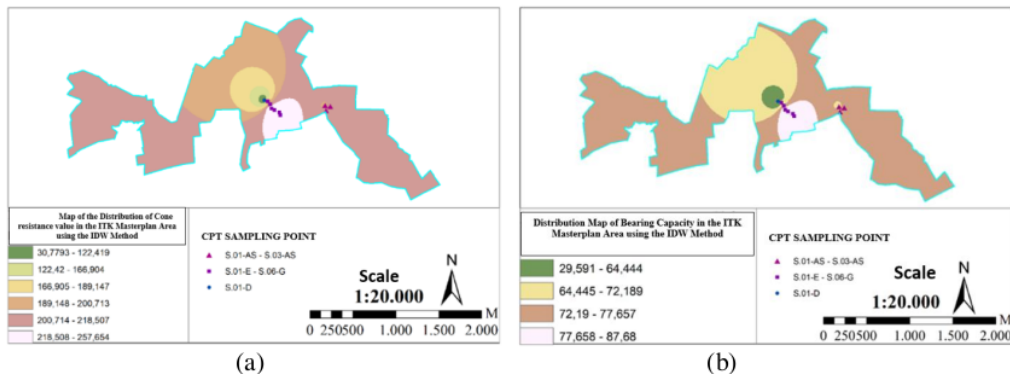
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3.2.2 IDW method

The analysis using the IDW method using a power value of 2 shows that the maximum value of cone resistance from the interpolation range is 257,654 kg/cm² and the minimum cone resistance value from the interpolation range is 30,7793 kg /cm². Meanwhile, the data samples' maximum and minimum values of cone resistance are 257,89 kg/cm². The maximum value generated by the interpolation analysis has a difference of about 0,236 kg/cm² and 28,32 kg/cm² which is smaller than the minimum value of cone resistance in the data sample used. Meanwhile, the minimum value generated by the interpolation analysis has a difference of about 2,46 kg/cm² which is greater than the value of the cone resistance in the data sample used. No value of the interpolation range is negative or too significant.



Source: Mapping Analysis of Conus Resistance.

Figure 3. (a) Map of the Distribution of Cone resistance value in the ITK Masterplan Area using the IDW Method (b) Distribution Map of Bearing Capacity in the ITK Masterplan Area using the IDW Method

Based on **Figure 3**, the mapping results of the IDW method can be seen that the mapping form from the interpolation results in the form of several circular polygons with varying distribution areas and can be seen surrounding the data samples of buildings D, E, F, G, and dormitory buildings. **Figure 3a** shows that most areas of the ITK master plan have soil consistency, namely hard with a q_c value of around 40,001 – 257,654 kg/cm². **Figure 3b**, indicating that the maximum value of the bearing capacity of the interpolated range is about 87,68 tons and the minimum value of the bearing capacity of the interpolated range is about 29,591 tons. Meanwhile, the minimum value of the bearing capacity of the data sample is 29 tons, and the maximum value of the bearing capacity of the data sample is 87,77 tons. The maximum value generated by the interpolation analysis has a difference of about 0,09 Tons,

which is smaller than the maximum value of the bearing capacity of the data sample used. Meanwhile, the minimum value generated by the interpolation analysis has a difference of about 0,591 Tons, which is greater than the minimum value of the bearing capacity of the data sample. No value of the interpolation range is negative or too significant. The power value is one of the influences. The sample points used are close to each other to produce interpolation results that are close to the results on the sample data. The interpolation results close to the values in the sample data indicate that the IDW method can be used to interpolate the bearing capacity values in the ITK masterplan area. **Figure 3b** shows that the ITK masterplan area has hard soil on the foundation with a Q_{all} value of around 29,591 – 87,68 Tons

3.2.3 Spline With Barriers Method

The difference in interpolation results produced by the spline with barriers method has differences in visual mapping and capacity range obtained from the bearing results.

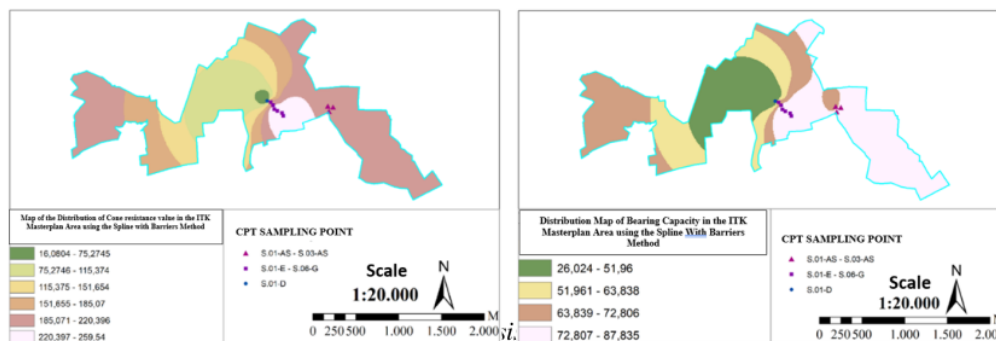


Figure 4. Map the Distribution of Cone resistance value in the ITK Masterplan Area using the Spline with Barriers Method.

The results of the interpolation analysis, which is about 259,54 kg/cm^2 and the minimum range of cone resistance, which is around 16,0804 kg/cm^2 . Meanwhile, the maximum and minimum values in the data samples used are approximately 257,89 kg/cm^2 and 28,32 kg/cm^2 , respectively. The maximum value generated by the interpolation analysis has a difference of about 1,65 kg/cm^2 more significant than the maximum value of cone resistance in the data sample used. Meanwhile, the minimum value generated by the interpolation analysis has a difference of about 12,24 kg/cm^2 which is smaller than the minimum value in the sample data.

The difference generated by the maximum value of the interpolation analysis with the data sample used is not so far from the sample value used. However, the difference generated by the minimum value of the interpolation analysis with the sample data results in a relatively

significant difference. Based on **Figure 4a**, it can be seen that the mapping form from the interpolation results produces several circular cut polygons that surround the sample points of the D, E, F, and G buildings with different colors, radius distances, and ranges of cone resistance results. The resulting polygons are spread only partially with a vast radius distance because this method has a menu of input barriers. This research does not input the data because there is no limit to anything in the analysis, so the resulting mapping forms circular polygons that are more widely spread compared to the Kriging and IDW methods. **Figure 4** shows that most areas of the ITK master plan have soil consistency, namely hard, with a q_c value of around 40,001 – 259,54 kg/cm². Based on the results of the interpolation **Figure 4b**, the maximum range value of the bearing capacity from the results of the interpolation analysis is about 87,835 Tons, and the minimum range value of the bearing capacity is about 26,024 Tons. Meanwhile, the maximum and minimum values in the data samples used are about 87,77 tons and 29 tons, respectively. The maximum value generated by the interpolation analysis has a difference of about 0,065 Tons, which is greater than the maximum value of the bearing capacity of the data sample used. Meanwhile, the minimum value generated by the interpolation analysis has a difference of about 2,976 tons, which is smaller than the minimum value of the bearing capacity of the data sample. In this study, the smooth value used is one because the results of the interpolation range value will be closer to the bearing capacity value of the data sample if the smooth value used is high. If the smooth value can affect the difference in the value of the interpolation range that will be generated, then the difference in the visual mapping obtained is influenced by the parameters of the tools and the number of samples used, namely input barriers or used as limiting data. **Figure 4b** shows that the ITK masterplan area has hard soil on the foundation with a Q_{all} value of around 26,024 – 87,835 Tons.

4. Conclusion

Analysis of the soil carrying capacity shows that the Q_{all} in the area is 26,024 – 87,835 tons, with the type of foundation soil being dense and the q_c value being 16,0804-259,54 kg/cm² with soil consistency being stiff, very stiff, and hard. Based on the mapping, it is known that the IDW method is the most suitable method according to the field data. The values of the q_c indicate this and Q_{all} ranges closest to the sample data used so that the mapping of bearing capacity and cone resistance values using the IDW method can be used as an initial approach in planning foundations at the areas where bearing capacity and cone resistance values have not been sampled.

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