Analysis of Bearing Capacity and Foundation Settlement of Luan Linggi Bridge, Aceh Province, Indonesia

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Abstract. A bridge is a structure made to cross a ravine or obstacle such as a river, railroad, or highway. The bridge consists of an upper structure and a lower structure. The upper structure of a building must be able to be supported by its own lower structure, namely the foundation. There are two types of foundations, namely shallow foundations and deep foundations. The planning of a foundation is said to be correct if the load that is forwarded by the foundation to the ground does not exceed the strength of the soil. Luan Linggi Bridge is one of the bridges that uses deep foundations in the form of pile foundations. This bridge is located in Luan Linggi Village, East Simeulu District, Simeulue Regency, Aceh Province, Indonesia. Due to the 2004 Tsunami disaster, the bridge pillars were broken and the abutments shifted, so the bridge could no longer be used. So, the bridge was redesigned in 2015 and rebuilt in 2021. This study aims to determine the value of the bearing capacity of a single foundation, the value of the bearing capacity of the group foundation, and the foundation settlement. This research uses N-SPT data, soil physical and mechanical properties, and detailed engineering design (DED). The method used to calculate the bearing capacity of the foundation is the Luciano Decourt method, while the single foundation settlement uses the Vesic method. The results obtained from this research are the bearing capacity and settlement value of the pile foundation with a diameter of 40 cm and a depth of 22 m. The ultimate bearing capacity value of the single foundation obtained is 375,228 tons, the permit bearing capacity value of the single foundation is 125,076 tons, the bearing capacity value of the group foundation obtained is 5,887,727 tons. The elastic settlement value of the foundation using the Vesic method is 2,88 cm, and the settlement value of the group foundation is 8,8 cm.

1 Introduction

The construction of a building consists of a lower structure and an upper structure. The foundation is the lower structure that transmits the load of the upper structure into the soil below without causing soil shear collapse and excessive settlement [1] There are two types of foundations, namely shallow foundations and deep foundations. Pile is one type of deep foundation that forwards the building load to the soil layer. The choice of pile foundation is
determined by the building structure, construction method, and soil layer conditions [2]. According to their composition, piles may be classified as timber piles, concrete piles, and steel piles [3].

The Luan Linggi Bridge is one of the buildings that uses pile foundations as the lower structure. This bridge has a span of 50 m and a width of 9 m. This bridge connects the Sinabang-Sibigo road section, East Simeulue District and West Simeulue District. Before this bridge was rebuilt in 2021, there was a previous bridge that connected the two sub-districts. However, the bridge experienced a shift in the abutments and a fracture in the pillars due to the 2004 Tsunami disaster. In 2015, a survey was conducted on the old bridge and the survey results showed that the bridge was no longer suitable for use. Can be seen in Fig.1. The bridge was redesigned in 2015 and rebuilt in 2021.

Fig. 1. Old bridge condition (a) abutment; (b) pillar

The soil condition on this bridge based on the boring test results and N-SPT values has a layer of clay and clayey silt. Of the various types of soil, clay is a type of soil that has a low bearing capacity and large shrinkage growth [4]. This research aims to determine the value of bearing capacity and settlement on the pile foundation of this bridge. Calculation of bearing capacity and foundation settlement is important to determine the bearing capacity and settlement that can be carried by the foundation. This research uses the Luciano Decourt method to calculate the bearing capacity of the foundation and uses the empirical method to calculate the settlement.

2 Methodology

This research was conducted on the Luan Linggi Bridge located in Luan Linggi Village, East Simeulue District, Simeulue Regency, Aceh Province, Indonesia. This bridge is located at coordinates 2°30'58.22 "N and 96°20'51.79 "E. This location was chosen because this bridge is an important bridge that connects the Sinabang-Sibigo road which is located in two sub-districts, namely East Simeulue and West Simeulue. Previously there was an old bridge connecting the two sub-districts, but unfortunately due to the 2004 Tsunami there was a shift in the abutment on one side and a fracture in the bridge pillar which caused the old bridge to no longer be used. This bridge is an important bridge, therefore in 2015 a redesign was carried out and in 2021 the bridge was rebuilt. The research location can be seen in Fig.2.
This research uses secondary data in the form of detailed engineering design (DED), N-SPT data, and laboratory testing data (physical and mechanical properties). The calculation of single bearing capacity is done by Luciano Decourt method which requires N-SPT data and then proceeds to calculate the bearing capacity of group foundation and settlement, both single foundation settlement and group foundation settlement. The pile plan can be seen in Fig.3.

The data of Luan Linggi Bridge, are as follows and the profile plan can be seen in Fig.4.

a. Bridge type : warren truss
b. Length : 50 m
c. Width : 9 m
d. Bridge floor width : 7 m
e. Pavement floor width : 1 m (left and right)
f. Segment width : 5 m
g. Segment height : 6 m
h. Pile diameter : 40 cm

Fig. 4. Plan profil

2.1 Ultimate bearing capacity

Foundation is an important part of a building structure. The stability of a structure depends on the stability of the supporting soil. There are two important factors that must be considered for the foundation, namely the foundation must be stable against shear collapse of the supporting soil and the foundation must not decrease beyond the tolerance limit to avoid damage to the structure [3].

Piles are usually used to transmit the load of the upper structure into the soil and rigid layer. The planning of pile foundations is not only sufficient with static methods, but also requires empirical knowledge and test results of piles in actual locations [5]. The bearing capacity of piles is the ability or capacity of piles to support loads. The bearing capacity of piles can be calculated using static methods and dynamic methods. The static method is a method that uses the principles of classical soil mechanics based on the results of laboratory tests and field tests [6].

One of the static methods for calculating the bearing capacity of piles is the Luciano Decourt method. Luciano Decourt method is one of the methods that can be used for various types of soil. This method is a refinement of the Meyerhoff method because the Luciano Decourt method has a more accurate value [7]. A study conducted a comparison between the value of Meyerhoff bearing capacity and the value of Luciano Decourt bearing capacity. From the research, it is obtained that the bearing capacity of the foundation calculated using the Luciano Decourt method has a smaller value than the bearing capacity using the Meyerhoff method [8]. Another study calculated the bearing capacity of the foundation using the Luciano Decourt method, from the calculation it was found that the value of the bearing capacity of the foundation produced by the Luciano Decourt method is close to the value of the bearing capacity produced by the PDA Test [9].

Here are the equation of the Luciano Decourt method:

\[ Q_u = Q_p + Q_s \]  
\[ Q_p = q_p \times A_p \]  
\[ Q_s = q_s \times A_s \]  
\[ q_p = N_p \times K \]  
\[ q_s = \frac{n_s}{3} + 1 \]

Where K is the coefficient of soil characteristics, with the value of K can be seen in Table1.
Table 1. Formatting sections, subsections and subsubsections

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>K (ton/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>12</td>
</tr>
<tr>
<td>Clayey Silt</td>
<td>20</td>
</tr>
<tr>
<td>Sandy Silt</td>
<td>25</td>
</tr>
<tr>
<td>Sand and Gravel</td>
<td>40</td>
</tr>
</tbody>
</table>


Group pile foundations are a set of piles that are installed closely together and are usually tied together at the top using a pile cap [10]. The bearing capacity of a group foundation is not always equal to the sum of the bearing capacity of the single piles in the group [11]. One of the methods used in the calculation of pile group efficiency is the Converse-Labarre method. A study compared the efficiency values of several methods, including Das, Converse Labarre, Los Angeles, Seiler-Keeney, and Feld methods. Of these methods, the Converse-Labarre method produces the lowest efficiency value [12]. Therefore, this study uses the Converse-Labarre method to calculate the efficiency value of the pile group.

\[
E_g = 1 - 6 \left( \frac{(n-1)m + (m-1)n'}{90mn'} \right) \tag{6}
\]

The ultimate bearing capacity value of group piles using the pile efficiency value can be calculated using the following equation.

\[
Q_g = E_g \times n \times Q_u \tag{7}
\]

2.2 Settlement

The term settlement is used to denote the movement at a given point of a building with respect to a fixed reference point. Foundation settlement in saturated fine-grained soils can be divided into three components, there are immediate settlement, primary consolidation settlement, and secondary consolidation settlement. Immediate settlement is the settlement produced by the distortion of the stressed soil mass, and occurs at a constant volume [13]. The settlement of a single pile must meet the allowable settlement requirement of the Reese & Wright equation which is 10% of the diameter [14]. The following are the equation for calculating the settlement of a single pile.

\[
S = Se_1 + Se_2 + Se_3 \tag{8}
\]

\[
Se_1 = \frac{(q_{wp} + q_{w})L}{A_pE_p} \tag{9}
\]

\[
Se_2 = \frac{q_{wp}E_p}{\Delta p} \tag{10}
\]

\[
Se_3 = \frac{q_{w}E_p}{\Delta p} \tag{11}
\]
Group piles are commonly used as foundations of various building structures, including those used in infrastructure organizations. Settlement and load analysis of pile groups is important in geotechnical and transportation engineering [15]. Generally, piles are used in the infrastructure of bridges, airports, ports, and flyovers. Group pile settlement can be calculated using the Vesic (1977) equation as follows.

\[ S_g = \frac{N_1}{\sqrt{D}} \times S \]  

(12)

3 Result and discussion

The research was conducted at Luan Linggi Bridge, East Simeulue District with 1 SPT testing point. The piles used are 40 cm in diameter with a pile depth of 22 m. Based on the N-SPT there are layers of clay and clayey silt, so using a K value of 12 tons / m² and 20 tons / m² for the calculation of the Luciano Decourt method. The Luciano Decourt method uses SPT data to generate bearing capacity values. The ultimate bearing capacity value generated by the Luciano Decourt method is 375,228 tons and the resulting allowable bearing capacity value is 125,076 tons. The efficiency value of the group foundation is 0.747 and the bearing capacity value of the group foundation is 5887,727 tons.

After obtaining the bearing capacity value of the foundation, the settlement value is calculated. There are two settlement values, there are the settlement of single piles and the settlement value of group piles. The decrease of a single pile in the form of an immediate decrease is worth 2.8 m. The group foundation settlement is 8.8 m. The settlement value of this single pile meets the requirements of Reese & Wrigth, which is an allowable settlement of 10% of the pile diameter.

4 Conclusion

Based on the results of calculations and analysis that have been carried out, the bearing capacity value of the skin friction is 285,379 tons and the bearing capacity value of the pile tip is 89,849 tons. It is concluded that the bearing capacity value of a single foundation based on the Luciano Decourt method is 375,228 tons and the allowable bearing capacity value using a safety factor of 3 is 125,076 tons. It is also obtained that the bearing capacity of the group foundation is 5887,727 tons. The settlement value obtained from the empirical method is 2.88 cm. The group pile settlement value is 8.8 cm.

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