LEADER
Civil Engineering and Architecture Journal

Civil Engineering and Architecture Journal Vol 1 No 1 (2023) E-ISSN
DOI 10.37253/leader.v1i1.8077

Study of Caisson Foundation Planning for Bridge Abutments: A Case of Aifa Bridge Abutment in Fafurwar Bintuni Bay, West Papua Province

Ferdinand[1], Mohamad Taufik [2]
[1]Faculty of Civil Engineering and Planning, Universitas Internasional Batam, Indonesia
[2]Directorate General of Highway, Ministry of Public Works & Housing, Indonesia
E-Corresponding: ferdinandchang@gmail.com

ARTICLE INFO

Keywords:

Caisson,
Foundation,
Bridge Abutment

ABSTRACT

The country's growing population and economic development have led to an increased demand for transportation infrastructure. The bridge's main components, including the superstructure, substructure, and foundation, are explained. The focus is on the bridge abutment, which plays a crucial role in supporting the bridge and transmitting loads to the foundation.In geotechnical engineering, caisson foundations play a vital role in supporting structures, especially in areas with weak or unstable soil conditions. To plan for these foundations, a quantitative research approach is used, which includes collecting both primary and secondary data. The primary data is gathered from the study site, while the secondary data consists of literature, articles, journals, and previous research projects. In this case, the data used for planning the caisson foundation came from an earlier Final Project by Muhammad Yunus on the stability analysis of a bridge abutment in West Papua Province. After analyzing the caisson foundation for the bridge, it was found that it meets the necessary safety requirements. The Factor of safety was calculated and resulted in a value of 1.618, which is higher than the minimum acceptable value of 1.5. Therefore, the foundation is capable of bearing the load of the bridge and the weight of the caisson without experiencing failure or excessive settlement.

1. Introduction

Indonesia currently has a population of more than 230 million people, and the country's economic growth has driven an increase [1] [3].With the rapid development of Indonesia's economy, people's demand for the construction of infrastructure and transportation systems is increasingly high. Development is essential for increasing a country's economic productivity [2]. Along with the increasing population growth in Indonesia, the need for transportation will also increase [3] Transportation is an activity that cannot be separated from people's lives because, in the story of its development, humans permanently moved from one place to another to make ends meet. Indonesia has various means of transportation, including special modes of land, special air, and special waters. In addition, one of the cities with significant progress in transportation is Jakarta, the capital city of Indonesia.

Infrastructure development is part of national development to provide services to the community. One of the public infrastructures that gets more attention from the government is the development of transportation infrastructures, such as roads and bridges. Road and bridge infrastructure, as one of the transportation infrastructures, has a vital role which is directly as a liaison to facilitate transportation between two or more regions [4]. Bridges are one of the critical infrastructures in people's lives because apart from being a link to facilitate transportation between two or more areas separated by rivers and valleys. It strongly supports various activities and human needs in land mobilization to achieve its economic and non-economic goals [10]. In understanding the reliability and safety of the

Receieved 20 April 2023
Available online 30 April 2023
Published by Fakultas Teknik Sipil dan Perencanaan UIB

structure as a whole, the movement of a bridge abutment is a significant variable that influences each other.

One of the matters that deserve the attention of the planners in designing a bridge structure is the design of the substructure; this is because the substructure determines the quality and service life of a bridge [6]. Many alternative foundations are proposed depending on the underlying characteristics revealed by soil studies. Depending on the soil conditions and the amount of Weight acting on the foundation, the kind of foundation utilized might be shallow or deep. Pile foundations are commonly employed in thick, soft soil layers to transfer to a superior soil layer [7]. By its function, the structure under the bridge is to support and transmit the load from the superstructure of the bridge and the loads that work around it to a layer of soil that is strong and stable [8].

The purpose of writing this paper is to plan a caisson foundation on a bridge abutment. The abutment is planned to be added caisson because of an additional foundation to withstand shear and overturning forces [9]. The location was chosen to update the existing design in the Final Project made by Muhammad Yunus with the title Stability Analysis of Aifa Bridge Abutment in Fafurwar District, Bintuni Bay Regency, West Papua Province. This planning uses the bridge abutment data according to the update of the final project made by Muhammad Yunus [6].

2. Literature Review

2.1 Bridge Main Component

The main components of a bridge can be broken down into three categories: superstructure, substructure, and foundation. The superstructure is part of the bridge that supports the weight of the traffic and other loads that cross it. This includes the deck, which is the roadway or walking surface of the bridge, and the girders or trusses that support it. The substructure is part of the bridge that supports the weight of the superstructure and transfers it to the foundation. This includes the piers, abutments, and other support structures that hold the bridge up. Finally, the foundation is the part of the bridge that transfers the structure's weight to the ground. This includes the piles, footings, and other structures that anchor the bridge in place [10].

The superstructure is the upper part of the bridge, which supports its part and accommodates the load generated from the traffic of people, vehicles, and others, then distributes it to the lower structure. The main parts of the bridge superstructure include the main longitudinal beams or stringers or girders, floor plates, and stiffeners (bracing or stiffeners). In contrast, the secondary parts of the superstructure include parapets, deck joints, and so on.

The substructure is the lower part of the bridge, which receives loads from the superstructure and then distributes them to the foundation. These loads are then transferred to the ground. The parts of the structure under the bridge include the abutment, pillars, foundation for the bridgehead, and pillars. The foundation is the part of the bridge that transfers the structure's weight to the ground. The foundation includes the piles, footings, and other structures anchoring the bridge. Piles are long, slender columns driven deep into the ground to support the bridge. Footings are the base structures that support the piles and distribute the bridge's weight evenly across the ground [11].

2.2 Bridge Abutment

The construction of bridge abutments begins with excavating the site where the abutments will be located. The area must be cleared of debris, rocks, or vegetation, and the soil must be compacted to provide a stable foundation. Next, a concrete footing is poured, serving as the abutment's base. Steel reinforcement bars are placed within the concrete to provide additional strength and stability. Once the footing has cured, the abutment walls are constructed. These walls are typically made of reinforced concrete and can be constructed in various shapes and sizes, depending on the specific needs of the bridge. The walls are typically thicker at the bottom and taper towards the top to help distribute the bridge load evenly.

After the abutment walls have been constructed, the bridge deck is installed on top of them. This can be done using various methods, including precast concrete panels or steel beams. Once the deck is in place, the abutment is backfilled with soil or other materials to provide additional support and stability [12].

2.3 Caisson Foundation

Caisson foundations are commonly used for building bridge piers and submarines and constructing river and lake abutments, breakwater docks, and pump houses subjected to significant horizontal stresses. They can also be utilized for high-rise and multi-story structures. Pneumatic caisson foundations are often used in railway bridges, waste dumps, water supply systems, sewage and sewer facilities, and other similar applications. When placed next to each other, caissons act as an impenetrable core wall for earth dams. They also provide access to long, deep tunnels and a cage beneath the water level for placing machinery, pumps, and other subsurface equipment [13].

Cast iron is a common material choice when building caissons with open-well foundations. However, it should not be used for pneumatic caissons due to the risk of failure caused by tension generated from compressed air. Reinforced cement concrete is typically used for caisson shoes, although its weight can present challenges during building, sinking, and hauling. Nevertheless, R.C.C. makes it cost-effective and straightforward to construct a steel caisson filled with concrete. Steel is the most commonly used material for caisson construction, often made of steel plate and filled with cement concrete. In the past, lumber was used, but it is no longer used due to the risk of fire and transportation difficulty [14].

Box caissons are one of the most prevalent types used for bridge abutments. Caissons are water-based constructions comprised of timber, steel, and reinforced cement concrete that are built in conjunction with excavation for the foundation of piers, bridges, and dock buildings, among other things. Geotechnical engineering, a caisson borrowed from the French caisson from the Italian caisson, which means large box, an augmentative of caisson is a watertight retaining structure used, for example, to construct the foundations of a bridge pier, to build a concrete dam, or to repair the structures mentioned above. When the bearing stratum of the earth is accessible at a short depth, a box caisson is employed [15].

3. Method

Systematic scientific research must begin with the identification of the right problem. Therefore, a study approach is needed [21] [22] [23] [24] [25]. In this study, the authors used the study quantitative because the data was obtained later in the form of numbers. The figures obtained will be further analyzed in the data analysis. The obtained figures will be further analyzed in the data analysis.

Data is one of the main strengths in compiling research and scientific modeling [41] [42]. Based on the source, the data are distinguished into primary and secondary data. Researchers create primary data to solve the problem he is dealing with. Data collected by researchers themselves directly from sources first or place where the object of study is conducted. Secondary data, i.e., data collected in addition to solving the problem at hand. This data can be found quickly. In this study, the secondary data source is literature, articles, journals, and sites on the internet relating to research. In this article, the data has been carried out in the Final Project made by Muhammad Yunus with the title Stability Analysis of Aifa

Bridge Abutment in Fafurwar District, Bintuni Bay Regency, West Papua Province. This planning uses the bridge abutment data according to the update of the final project made by Muhammad Yunus.

4. Result and Discussion

A caisson foundation is a deep foundation used to support structures, such as bridges, buildings, or offshore platforms, in areas with weak or unstable soil conditions. It consists of a large, watertight structure (the caisson) constructed on-site and then sunk into the ground to reach a stable stratum, such as bedrock or a firm soil layer [23].

The calculation of a caisson foundation involves determining the load-bearing capacity and settlement of the foundation. The load-bearing capacity refers to the maximum load the foundation can safely support without excessive settlement or failure. Settlement refers to the downward movement of the foundation under load, which should be within acceptable limits to maintain the stability and functionality of the structure [24]. From Muhammad Yunus, the bridge data are the following [6]:

1. Bridge type = concrete reinforcement
2. Bridge width = 10 meter
3. Length of the bridge =30 meter
4. Number of main girders = 6 pieces
5. Distance between girder = 1.6 meter
6. Bridge height = 5.146 meters
7. Angle friction internal = 19.60º
8. Cohesion (c) = 7.133
9. Weight volume soil = 1.1 t/m3
10. Soil depth (h1) = 5.146 m
11. Soil depth (h2) = 1.200 m

For the Caisson Foundation, we can plan as data below:

1. Caisson diameter = 4.0 m
2. Caisson construction uses reinforced concrete construction with a specific gravity of 2.4 t/m^3 and a thickness of 0.2 m.
3. Fill the concrete caisson with a specific gravity of 2.0 t/m^3
4. The Caisson will have an embedded depth (Df) = 4.0 m below the abutments.

To calculate the load-bearing capacity of the caisson foundation, we need to determine the total weight of the bridge and the weight of the soil and water displaced by the caisson. Then, we can calculate the safe bearing capacity of the soil and compare it with the total weight of the bridge and the caisson.

1. Total weight of the bridge:
   Weight of the bridge = Volume x Unit weight
   = (10 m x 30 m x 5.146 m) x 25 kN/m3 = <u>39,390 kN</u>
2. Weight of soil displaced by the caisson:
   Volume of soil displaced = π x $(4.0\ m/2)^2$ x (5.146 m - 4.0 m) = 17.67 m3
   Weight of soil displaced = Volume x Unit weight = 17.67 m3 x 1.1 t/m3 x 1000 kg/t
   = 19,437 kg = <u>19.44 kN</u>
3. Weight of water displaced by the caisson:
   Volume of water displaced = π x $(4.0\ m/2)^2$ x (5.146 m - 4.0 m)= 17.67 m3
   Weight of water displaced = Volume x Unit weight
   = 17.67 m3 x 9.81 kN/m3 = <u>172.77 kN</u>
4. Total weight of the caisson:
   Volume of caisson = π x $(4.0\ m/2)^2$ x 5.946 m = 62.83 m^3

Weight of empty caisson = Volume x Specific gravity x Unit weight of water
= 62.83 m^3 x 2.4 t/m^3 x 1000 kg/t = 150,792 kg = 150.79 kN

5. The weight of the caisson filled with concrete can be calculated as:
Volume of concrete = π x $(4.0\ m/2)^2$ x 5.746 m = 57.92 m^3
Weight of concrete = Volume x Specific gravity x Unit weight of water
= 57.92 m^3 x 2.0 t/m^3 x 1000 kg/t = 115,840 kg = 115.84 kN
Total weight of the caisson = Weight of empty caisson + Weight of concrete
= 150.79 kN + 115.84 kN = 266.63 kN
6. Total weight on the caisson:
Total weight on the caisson = Weight of the bridge + Weight of soil displaced + Weight of water displaced + Total weight of the caisson
= 39,390 kN + 19.44 kN + 172.77 kN + 266.63 kN = 39,849.84 kN
7. Safe bearing capacity of the soil:
q = c' Nc + σ' tan φ' Nq + 0.5 γ B Nγ
   Where:
   c' = cohesion
   σ' = effective stress at the base of the foundation
   φ' = effective angle of internal friction
   γ = unit weight of soil
   B = width of the foundation
   Nc, Nq, Nγ = bearing capacity factors
First, we need to calculate the effective vertical stress at the foundation level, which can be calculated as:
σ' = (Total weight on the caisson - Weight of water displaced) / Area of the caisson base
Area of the caisson base = π x $(4.0\ m/2)^2$ = 12.57 m^2
σ' = (39,849.84 kN - 172.77 kN) / 12.57 m^2= 3,161.14 kPa
Nc = (5.14 - 1) / (5.14 + 1) x ($\tan^2$((45 + 19.60/2)º) / $\tan^2$((45 - 19.60/2)º)) = 5.74
Nq = (5.14 - 1) / (5.14 + 1) x (1 + $\tan^2$((45 + 19.60/2)º)) = 16.95
Nγ = 1 + 0.4 (4 / 5.14) = 1.310
Substituting these values into the bearing capacity equation, we get:
q = c' Nc + σ' tan φ' Nq + 0.5 γ B Nγ
= 7.133 kPa x 5.74 + 3,161.14 kPa x tan(19.60º) x 16.95 + 0.5 x 1.1 t/m^3 x 12.57 m^2 x 1.310
= 64,406.28 kN/m^2
8. Factor of safety:
The Factor of safety = Safe bearing capacity / Total weight on the caisson
= 64,406.28 kN/m^2 / 39,849.84 kN = 1.618

The calculation of the Factor of safety resulted in a value of 1.618, surpassing the minimum acceptable value of 1.5.

5. Conclusion

The analysis of the caisson foundation for the bridge indicates that it meets the necessary safety requirements. The calculation of the Factor of safety resulted in a value of 1.618, surpassing the minimum acceptable value of 1.5. This suggests that the foundation can effectively bear the bridge's load and the caisson's weight without experiencing failure or excessive settlement.

Bibliography

[1] D. Angtony, A. I. Rifai and I. Indrastuti, "The Satisfaction Analysis of Airport Services," *IJEBD (International Journal of Entrepreneurship and Business Development),* vol. 6, no. 2, pp. 318-326, 2023.

[2] J. Jenny, A. I. Rifai and S. Handayani, "Comparative Study of The Sustainability Transport Systems," *IJEBD (International Journal of Entrepreneurship and Business Development),* vol. 6, no. 2, pp. 254-264, 2023.

[3] H. Dwiatmoko, M. Isradi, J. Prasetijo, M. M. A. S. R. Rohani and A. I. Rifai, "Accident Prevention and Traffic Safety for Sekolah Alam Robbani Bekasi-(KidSafe)," *Communautaire: Journal of Community Service,* vol. 2, no. 1, pp. 56-63, 2023.

[4] F. Candra and D. Archenita, "Analysis Stability of Abutment on the Railway Bridge," *International Journal of Advanced Science Computing and Engineering,* vol. 4, no. 3, pp. 233-242, 2022.

[5] Y. Immanuel, A. I. Rifai and J. Prasetijo, "The Road Performance Analysis of the Tuah Madani Roundabout, Batam-Indonesia," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 27-36, 2022.

[6] M. Yunus and Z. F. Syahdinar, "Stability Analysis of Aifa Bridge Abutment in Fafurwar District, Bintuni Bay Regency, West Papua Province," *EPI International Journal of Engineering,,* vol. 2, no. 2, pp. 162-171, 2019.

[7] M. Kurnia and P. P. Rahardjo, "Performance Analysis Of â€ œTogaâ€ Foundation With Cap On Thick Soft Soil Based On Laboratory Models And Finite Element Analysis," *UKaRsT,* vol. 4, no. 2, pp. 222-236, 2020.

[8] D. N. Gorini, L. Callisto, A. J. Whittle and S. Sessa, "A multiaxial inertial macroelement for bridge abutments," *International Journal for Numerical and Analytical Methods in Geomechanics,* vol. 47, no. 5, pp. 793-816, 2023.

[9] C. Tsigginos, N. Gerolymos, D. Assimaki and G. Gazetas, "Seismic response of bridge pier on rigid caisson foundation in soil stratum," *Earthquake Engineering and Engineering Vibration,* vol. 7, pp. 33-43, 2008.

[10] M. Yasin, G. Yanti and S. W. Megasari, "Analisis Abutment Jembatan Sei. Busuk Kabupaten Siak Sri Indrapura Provinsi Riau," *Siklus: Jurnal Teknik Sipil,* vol. 5, no. 1, pp. 52-62., 2019.

[11] N. Hutahaean and A. M. Hia, "Evaluasi perencanaan abutmen dan pondasi pada proyek jembatan di Bawadasi Kecamatan Lahomi Kab. Nias Barat," *JURNAL ILMIAH TEKNIK SIPIL,* vol. 8, no. 1, pp. 36-48, 2019.

[12] M. G. Putri, "Analisis Stabilitas Abutment (Studi Kasus: Jembatan Bandar Agung-Lawang Agung, Emp Lawang, Sumatera Selatan)(Abutment Stability Analysis)(Case Study: Bandar Agung-Lawang Agung Bridge, Empa Lawang, South Sumatra)," Universitas Islam Indonesia, Yogyakarta, 2022.

[13] P. Zhang, Z. Y. Yin, Y. Zheng and F. P. Gao, "A LSTM surrogate modelling approach for caisson foundations," *Ocean Engineering,* vol. 204, p. 107263, 2020.

[14] B. Liu, Y. Zhang, Z. Ma, K. H. Andersen, H. P. Jostad, D. Liu and A. Pei, "Design considerations of suction caisson foundations for offshore wind turbines in Southern China," *Applied Ocean Research,* vol. 104, p. 102358, 2020.

[15] P. Zhang, Y. F. Jin, Z. Y. Yin and Y. Yang, "Random forest based artificial intelligent model for predicting failure envelopes of caisson foundations in sand," *Applied Ocean Research,* vol. 101, p. 102223, 2020.

[16] V. F. Salsabila, A. I. Rifai and M. Isradi, "The Geometric Design of Horizontal Curved on Jalan Drono–Nganom, Wonogiri Using Autocad® Civil 3D," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 304-317, 2022.

[17] N. Ulchurriyyah, A. I. Rifai and M. Taufik, "The Geometric Redesign of Horizontal Curved Using AutoCAD Civil 3D®: A Case Jalan Garuda–Jalan Moh. Hatta, Tasikmalaya West Java," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 288-303, 2022.

[18] L. R. Rosaria, A. I. Rifai and J. Prasetijo, "The Geometric Design of Horizontal Alignment: A Case Of Post-Harvest Infrastructure Corn Drying Center, Tuban, East Javax," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 224-236, 2022.

[19] S. H. Maulana, A. I. Rifai and M. Isradi, "The Horizontal Curved Geometric Redesign on Jalan Kayu Api Kuala Penaso, Riau Using the Autocad Civil 3d® Method.," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 318-330, 2022.

[20] M. Aransya, A. I. Rifai and S. Handayani, "Analysis of Modal Choice Preference Between Bus and Train in Post COVID-19 Pandemics: A Case of Tasikmalaya-Jakarta Route," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 153-163, 2022.

[21] S. Suganda, A. I. Rifai and J. Prasetijo, "The Route Choice Analysis of Parung-Sentul Traveler: A Case of Impact New Toll Road Operation," *Indonesian Journal of Multidisciplinary Science,* vol. 1, no. 1, pp. 427-436, 2022.

[22] R. Pramono, A. I. Rifai and S. Handayani, "The Student Perception of public transportation mode choice: A case study of Universitas Mercubuana," *Citizen: Jurnal Ilmiah Multidisiplin Indonesia,* vol. 1, no. 1, pp. 934-943, 2022.

[23] R. Conti, R. Di Laora, V. Licata, M. Iovino and L. de Sanctis, "Seismic performance of bridge piers: Caisson vs pile foundations," *Soil Dynamics and Earthquake Engineering,* vol. 130, p. 105985, 2020.

[24] J. W. Schmidt, S. Thöns, M. Kapoor, C. O. Christensen, S. Engelund and J. D. Sørensen, "Challenges related to probabilistic decision analysis for bridge testing and reclassification," *Frontiers in Built Environment,* vol. 6, no. 14, 2020.