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Pile Capacity Analysis for Unloading Jetty Structures at The Coal Fired-Steam Power Plant (CFSPP) Mamuju, West Sulawesi

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Abstract: The Mamuju Coal-Fired Steam Power Plant (CFSPP), is located in Mamuju Regency, West Sulawesi Province. The plant was comercially operated in 2019. One of the main facilities at Mamuju CFSPP is the unloading jetty. The top structure of existing unloading platform were made of monolithic concrete platform, supported by pile foundations. This research aims to analyze the axial bearing capacity and assess the stress ratio acting on the piles used in the unloading jetty platform by applying different configuration of top structure. The axial bearing capacity was calculated using the Meyerhof method, and structural modeling and analysis were conducted using SAP2000 software. The results indicate that the ultimate bearing capacity (Qu) and allowable bearing capacity (Qall) for the unloading platform structure are 4,317.916 kN and 1,727.166 kN respectively. The maximum axial force of the unloading platform is 2,964.30 kN. Furthermore, the stress ratio was found to be less than one, indicating that the pile foundation is operating within safe limits based on the ultimate bearing capacity. However, further evaluation is recommended to assess the potential for load increases for the alternative configuration of top structure.
Keywords: *Unloading Jetty, Axial Bearing Capacity, Steel Pipe Pile, SAP2000*

1. Introduction

The Coal-Fired Steam Power Plant (CFSPP) generates electricity by harnessing the kinetic energy of steam. One significant advantage of CFSPPs lies in their ability to operate continuously, as long as coal as the primary fuel is available. This makes them more reliable than power plants reliant on natural conditions, such as hydro power plants.

This research focuses on Mamuju's CFSPP, located in Mamuju, West Sulawesi, with a generating capacity of 2x25 MW, which is comercially operated in 2019. The plant receives its coal supply via a specialized jetty, which comprises several critical structural components, including the unloading platform, mooring dolphins, and a breasting dolphin, along with other essential facilities. A noteworthy concern with the current jetty configuration is the 50 m long main platform, which is significantly shorter than the coal barge's overall length of 92 m. This disparity raises concerns regarding the load-bearing capacity and stress distribution of the jetty's pile foundation, necessitating a thorough structural analysis to ensure the stability and safety of the unloading operations.

The top structure of the existing unloading jetty at Mamuju CFSPP was constructed using a monolithic casting method (see Figure 1.a), wherein the construction of the platform is

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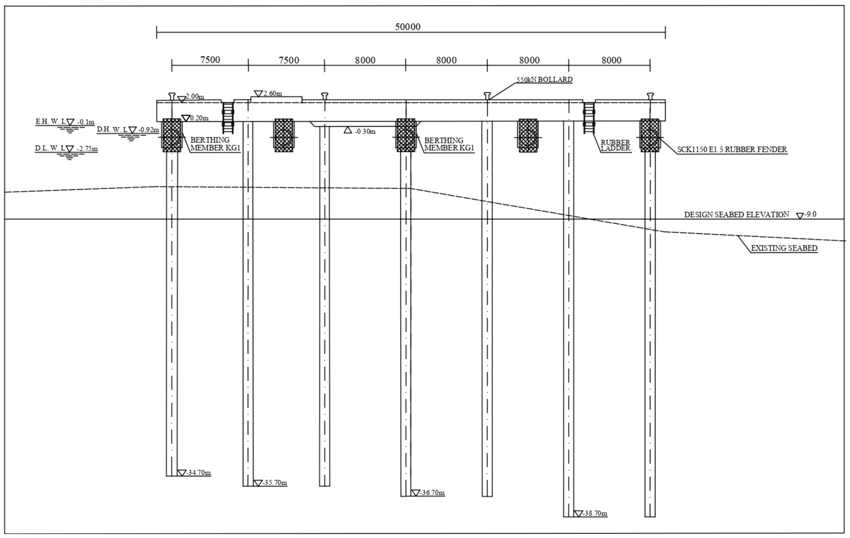
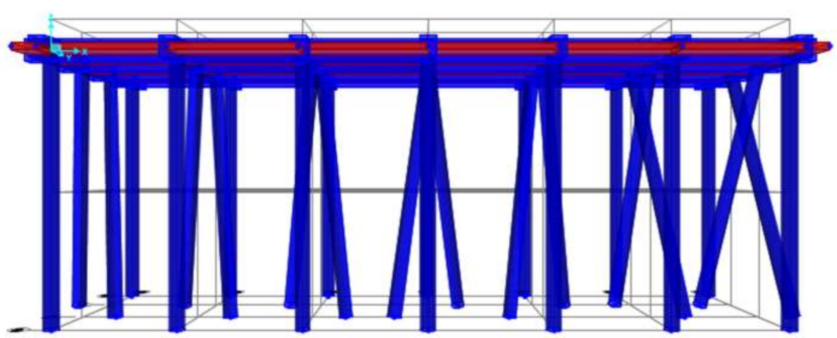
poured as a singular unit, devoid of beams and slabs. However, this research explores an alternative top structure configuration using SAP2000, incorporating beams and slabs (see Figure 1.b), which are absent in the existing design. The alternative design includes slabs with a thickness of 400 mm and beams of two distinct sizes (600 x 1250 mm for the overall structure, and 1000 x 1400 mm for the sections supporting the fixed grab unloader and fixed hopper). This difference in configuration allows a thorough analysis of the jetty's capacity under various load conditions, providing a more comprehensive understanding of its structural behavior.



(a)



(b)

Fig. 1. Existing Jetty Design (a), Alternative Jetty Design for SAP2000 Analysis (b)
Source: Researcher's Analysis (2024)

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This study aims to analyze the axial bearing capacity and stress ratio of the existing pile configuration of Mamuju CFSPP's jetty. By using Microsoft Excel and SAP2000 software, this research evaluates whether the current pile configuration is sufficient if an alternative configuration for the top structure is applied. The findings of this analysis will provide insight into the impact of different top structure configurations on the existing pile capacity. While the risk of excessive settlement was acknowledged, this study did not incorporate an in-depth geotechnical analysis or the monitoring of actual settlement data. The assumptions made regarding soil characteristics and settlement behavior are based on standard models and available data.

2. Literature review

The development of jetty infrastructure is a critical component of transportation and logistics, particularly for power plants that rely on continuous fuel deliveries, such as the Mamuju Steam Power Plant (Mamuju CFSPP). The jetty structure must be adequate to withstand various loads from docking ships, wind, currents, and seismic activities, all of which have the potential to impact the stability and functionality of the structure.

In analyzing the pile structure capacity at Mamuju CFSPP's jetty, this study employs the axial bearing capacity calculation method developed by Meyerhof (1976). Meyerhof's approach calculates the ultimate bearing capacity of piles based on soil friction and end-bearing capacity, which has been widely accepted in geotechnical engineering for assessing pile load capacities. Furthermore, structural analysis is conducted using SAP2000 software, which is extensively utilized in research to model loading conditions and analyze structural deformations and internal forces. The combination of these two methods provides a robust framework for analyzing the jetty's load-bearing capacity.

This study focuses on several major loads that affect the jetty's structure, including vertical loads, berthing loads, mooring loads, and seismic loads. Each of these loads plays a critical role in determining the overall stability and performance of the pile foundation. The research also references international and national standards, such as PIANC (2002), BS 6349, and SNI 1726 (2019) to ensure the analysis aligns with established design guidelines and field conditions.

Previous research underscores the importance of selecting the appropriate materials for jetty construction, such as steel for piles and concrete for superstructures, especially in marine environments like the jetty at Mamuju CFSPP. Steel piles are used due to their superior strength in supporting axial and lateral loads, though corrosion in the splash zone remains a risk that must be mitigated with proper material protection. Thus, this study contributes to ensuring the stability and safety of the Mamuju CFSPP's jetty and provides a foundation for further evaluation.

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3. Research method

This study employs a quantitative approach to evaluate the axial bearing capacity and analyze the performance of the pile structure under various load conditions for the unloading jetty at Mamuju CFSPP.

3.1. Data Collection

The data used in this research consists of secondary data obtained from relevant projects, standards, books, journals, and theses. The types of data collected for analysis include:

1. Pile Specifications: Information on the material characteristics of steel pipe piles used in the jetty structure was gathered to analyze their behavior under load.
2. Environmental Data: Wind, current, and tidal data from the site were collected to model the environmental loads acting on the structure.
3. Design Data: Data regarding the layout of the jetty, vessel dimensions, and fender specifications were obtained to simulate the actual operating conditions.

3.2. Instruments and Tools

The following tools were employed for the analysis:

1. Microsoft Excel: This software was used to calculate the loading conditions and estimate the axial bearing capacity of the pile in the structure.
2. SAP2000: Structural modeling and analysis of the pile foundation were conducted using SAP2000. The software provided insights into the behavior of the piles under various loading scenarios, including vertical, berthing, mooring, and seismic loads.

3.3. Research Variables

Independent Variables:

1. Pile material: Steel pipe piles; Yield Strength (Fy) = 240 MPa
2. Pile diameter: 1000 mm; thickness: 18 mm
3. Soil Characteristics: Clay
4. Applied loading: Berthing load, mooring load, seismic load

Dependent Variables:

1. Axial bearing capacity of the piles
2. Stress ratio of the piles

3.4. Data Analysis

The following steps were carried out in the analysis:

1. Load calculations: the environmental and structural loads acting on the jetty were calculated, including vertical loads, berthing loads, mooring loads, and seismic loads.
2. Axial capacity estimation: The Meyerhof method was used to estimate the axial

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bearing capacity of the piles, considering both friction along the pile surface and the end-bearing capacity.

3. Structural modeling: The jetty and pile foundation were modeled in SAP2000 to simulate the applied loads and analyze the stress ratio and the axial load acting on the piles.

4. Results and discussion

4.1. Vertical Load

Vertical loads consist of the dead load (self-weight of the structure) and live loads, such as equipment or operational machinery placed on the jetty. The vertical loads include:

1. Dead load: Primarily from structural elements such as steel pipe piles, platforms, and fixed equipment such as the fixed grab unloader (2400 kN) and fixed hopper (250 kN)
2. Live load: Includes the uniformly distributed load (UDL = 20 kN/m^2) and the weight of the mobile truck crane (431.5 kN)

4.2. Berthing Load

Berthing load occurs when a vessel berths to the jetty structure, transmitting forces through fenders into the structure. The berthing load is calculated based on the vessel's displacement, approach velocity, and fender specifications. The energy the fender system absorbs is essential in mitigating forces exerted on the piles. The berthing load calculations for Mamuju Jetty are shown in Table 1 as follows:

Table 1

Berthing Load Calculations

Berthing Load Parameters		
Vessel Type	Barge	General Cargo (assumed)
Deadweight Tonnage (DWT)		10,000
Length Overall (L_{OA})		92.0 m
Beam (B)		31.5 m
Draft (D)		5.3 m
Vessel Approach Speed (V_B)		0,15 m/s
Sea Water Density (ρ)		1,025 kg/m^3
Vessel Displacement (M_D)		11,808 t
Block Coefficient (C_B)		0.75
Added Mass Coefficient (C_M)		0.35
Eccentricity Coefficient (C_E)		0.95

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Berth Configuration Coefficient (C_C)	1.0
Softness Coefficient (C_S)	1.0
Berthing Energy	
Normal Berthing Energy (E_N)	44.63 kNm
Abnormal Berthing Energy (E_A)	78.10 kNm

4.3. Mooring Load

Mooring load is caused by tension forces from the moored vessel. These forces are affected by wind and current action which create lateral loads on the vessel and are transmitted to the jetty structure. The calculation results of mooring loads are summarized in Table 2.

Table 2
Mooring Load Calculations

Mooring Load Parameters							
Mooring: Wind Forces							
Wind Speed (V_W)				11.98 m/s			
Wind Pressure at 30° (ρ)				1.1703 kg/m^3			
Wind Area (Interpolated)				Transversal		Loaded	1023.2
						Ballasted	1388.7
				Longitudinal		Loaded	259.7
						Ballasted	340.1
Transversal				Longitudinal			
Loaded		Ballasted		Loaded		Ballasted	
90°	58 kN	90°	83 kN	0°	4.79 kN	0°	4.56 kN
				180°	-5.67 kN	180°	-8.57 kN
Mooring: Current Forces							
Current Speed (V_C)				0.16 m/s			
Sea Water Density (ρ)				1,025 kg/m^3			
Vessel Draft (D)				5.3 m			
Length Overall (L_{OA})				92.0 m			
Lateral				Longitudinal			
90°		0.003 kN		0°		0 kN	
				180°		0 kN	

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Mooring Load Parameters	
Maximum Mooring Load	
Transversal	83.003 kN
Longitudinal	4.79 kN

4.4.Seismic Load

The Mamuju CFSPP is located in a highly seismic zone. The seismic load was analyzed using the response spectrum method. The seismic design parameters were derived from the Indonesian Design Spectrum (SNI 1726-2019) as shown in Table 3.

Table 3
Seismic Response Spectrum Parameters

Design Seismic Response Spectrum	
Soil Site Class	SE- Soft Soil (Soft Clay)
PGA (g)	0.487
S_S (g)	0.707
S_1 (g)	0.272
F_a (g)	1.369
F_v (g)	2.942
Sd_s (g)	0.645
Sd_1 (g)	0.532
T_0 (s)	0.1651
T_S (s)	0.8256

4.5.Axial Bearing Capacity

The soil type at the Mamuju CFSPP's unloading jetty is dominantly composed of soft clay. Structures built on soft clay are often subjected to specific challenges and is known for their tendency to settle over time under sustained loads which can impact structural stability.

The capacity of the piles in soft clay is governed by both the ultimate bearing capacity (Qu) and the allowable bearing capacity (Qall). The ultimate bearing capacity includes both the skin friction (along the length of the pile) and the end-bearing capacity (at the pile tip). For soft clay soil, the end-bearing capacity is usually low, so a significant portion of the load is resisted by skin friction.

The axial bearing capacity of the steel pipe piles supporting the unloading platform was calculated using the Meyerhoff method for clay soil by considering both end-bearing and skin friction contributions. The total embedded pile length is 33.27 m and the calculated

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results for the unloading platform's pile foundation show that the ultimate bearing capacity (Qu) is 4,317.916 kN, while the allowable bearing capacity (Qall) is 1,727.166 kN.

4.6. SAP2000 Analysis

The structural analysis of the unloading platform was carried out using SAP2000 software to model the pile behavior under various load conditions, with a fixity point set at 8.76 meters below seabed. The primary objective of the study was to assess the axial loads acting on the piles. The analysis results indicate that the maximum axial load for the piles supporting the unloading platform is 2,964.30 kN, which exceeds the allowable bearing capacity but remains within the ultimate bearing capacity.

In addition to axial load assessment, the stress ratio of the piles was also analyzed. The stress ratio is a critical indicator of a structure's performance, with a value below 1 signifying safe operation and a value of 1 or above indicating potential overstressing. The stress ratio for the unloading platform was found to be 0.251419, comfortably below the critical value of 1.

4.7.Pile Capacity Analysis

The maximum axial load obtained from the analysis on SAP2000 is compared with the allowable bearing capacity (Qall) of the piles. While the axial load exceeds the allowable capacity, it remains below the ultimate bearing capacity (Qu). Indicating that, while the piles are subjected to significant forces, it still has sufficient reserved strength to prevent structural failure. This analysis confirms that the pile structure operates within its design capacity limits and that the piles are not at risk of structural failure under current operational loads. The analysis also indicated that the stress ratio is below 1, affirming that the unloading platform structure is functioning safely within its design limits.

5. Conclusion

Based on the axial bearing capacity calculation and analysis performed using SAP2000, it can be concluded that the pile foundation of the unloading jetty at Mamuju CFSPP is safe and capable of withstanding the applied loads with alternative top structure configuration, resulting in pile stress ratio below 1.0 and the axial load within the ultimate bearing capacity.

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