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Structural Design of a 2,000 DWT Tanker Jetty with Deck-on-Pile System at Kabil, Batam Island

Panusunan Panusunan[1*], Sumitro D.P. Simanungkalit[2], Januarto Januarto[3], Herlina Suciati[4]
Department of Civil Engineering, Universitas Batam, Batam, Indonesia[1,2,3,4]
panusunan2010@gmail.com

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Coresponding author:
Panusunan
Department of Civil Engineering,
Universitas Batam, Batam, Indonesia
E-mail: panusunan2010@gmail.com

ABSTRACT
Purpose: This study designs a 2,000 DWT tanker jetty at Kabil, Batam Island, to support offshore marine loading operations.
Methodology: This study uses site investigation data (topography, soil, tides, and waves) and secondary data from BMKG and related authorities. Structural design and analysis were conducted using ETABS based on Indonesian standards SNI 2847:2013 and SNI 03-1726-2002.
Results: The jetty adopted a deck-on-pile system with an elevation of +5.29 m. The structural elements, including beams, slabs, dolphins, and Ø600 mm steel piles (capacity 187.17 tons), satisfied the design loads with adequate safety factors. Fender and mooring systems were designed for a 2,000 DWT vessel.
Conclusions: The structure meets the strength and serviceability requirements under all load combinations, ensuring safe and efficient operation.
Limitations: This study excluded cost analysis, construction sequencing, environmental assessment, and dynamic seismic analysis.
Contribution: This research provides a complete structural design framework for deck-on-pile jetty systems in shallow offshore environments, which is applicable to similar port infrastructures in Indonesia.

Keywords: *Batam, Berthing Dolphin, Deck-On-Pile, ETABS, Jetty Design, Marine Structures, Mooring Dolphin, Pile Foundation, Tanker Terminal, 2000 DWT*

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1. Introduction

Batam Island, situated at the southern entrance to the Malacca Strait and adjacent to Singapore and Malaysia, constitutes one of Indonesia's most strategically important industrial zones. The island hosts concentrated heavy and light industrial activities, including steel manufacturing, shipbuilding, electronics, and petroleum product distribution, all underpinned by its designation as a Special Economic Zone (SEZ) under the Indonesian government policy (Azman & Satriawan, 2025; Karim, 2020). The industrial ecosystem depends critically on reliable marine transportation infrastructure, particularly for the supply of liquid fuel and industrial gases, such as oxygen, nitrogen, carbon dioxide, argon, and acetylene, which are essential inputs across the offshore, manufacturing, and energy sectors (Koronides, Michailides, Stylianidis, & Onoufriou, 2024).

The offshore industry sector in Batam has experienced sustained growth, expanding the demand for dedicated marine loading and unloading facilities capable of servicing tanker vessels transporting petroleum products and liquefied industrial gases to various industries and fuel distribution points (SPBU) throughout the island (Chandra, Satriawan, & Dewi, 2025; Setyawan & Siallagan, 2025). While existing port facilities primarily serve container and general cargo operations, the specialized requirements of tanker operations, including safe cargo transfer systems, chemical-resistant deck surfaces, dedicated mooring arrangements, and structural capacity to withstand berthing impacts from loaded tankers, necessitate purpose-designed jetty infrastructure (Koronides, Michailides, & Onoufriou, 2024).

The Kabil area on Batam's eastern coast has been identified as a suitable location for a dedicated tanker terminal servicing fuel supply operations for the island's industrial consumers. Hydrographic conditions at Kabil, characterized by relatively shallow nearshore waters requiring structural extension offshore to achieve adequate draft clearance, make the deck-on-pile pier jetty (pier type) the most technically appropriate and economically feasible structural configuration (Anisa, 2025; Bhimasta, Surya, & Pramudita, 2025). This configuration, which uses steel pipe piles as the primary foundation system with a reinforced concrete deck platform above, provides a combination of structural robustness, durability, and constructability required for the site conditions (Roeder, Stephens, & Lehman, 2018).

This study presents the complete structural design of a jetty facility for 2,000 DWT tanker vessels at Kabil, Batam, encompassing site characterization from primary field surveys and secondary oceanographic data, such as the determination of design environmental parameters (tidal levels, wave height, wind, and current forces), structural design of the jetty deck, trestle, and pile system; design of the berthing dolphin, mooring dolphin, and associated marine equipment; and verification of structural adequacy under governing load combinations using ETABS v9 structural analysis software.

2. Literature Review and Hypothesis/es Development

2.1 Jetty and Pier Design Principles

A port is defined as a sheltered water area equipped with marine terminal facilities, including berths, cargo handling equipment, transit storage, and vessel service infrastructure (Triatmodjo, 1996). Jetties and piers constitute the primary interface between maritime and terrestrial logistics systems, providing a structural platform from which vessels are loaded, unloaded, and serviced (Lee, Jo, Bergan, Pettersen, & Chang, 2016). The fundamental design challenge for any marine berthing structure is to accommodate the range of environmental and operational forces acting on the structure, such as wave action, tidal variation, wind loads, current drag, vessel berthing impacts, and mooring line tensions, while maintaining structural integrity and operational continuity over a service life typically exceeding 25 years (Arif, Khan, Ahmed, & Imtiaz, 2023).

Among the primary jetty structural configurations, the deck-on-pile (pier) type is particularly suited to sites characterized by soft or variable seabed conditions, moderate water depths, and where the avoidance of significant dredging is economically or environmentally desirable (Darmawan, Bayuaji, Anugraha, Saputra, & Victoriawan, 2024). In this configuration, the deck platform is elevated above the mean water level on a grid of driven piles, typically prestressed concrete, steel pipe, or steel H-section, which transfers all vertical and lateral loads to the foundation stratum. The deck-on-pile configuration offers several advantages over solid-fill alternatives, such as minimizing dredging requirements, preserving natural water circulation beneath the structure, and allowing future configuration changes without the irreversibility of reclaimed fill construction (Stefanakis, 2019).

In offshore and coastal engineering, the selection of deck-on-pile systems is strongly influenced by geotechnical variability and hydrodynamic exposure conditions (Edianto & Ashury, 2019). The flexibility of pile-supported structures allows them to better accommodate differential settlement and dynamic loading induced by waves, currents, and berthing. Moreover, in seismic-prone regions such as Indonesia, this structural system provides improved energy dissipation owing to its inherent ductility and reduced mass compared with massive gravity-based structures. The modular nature of pile-supported jetties facilitates phased construction, reduces construction risks in marine environments, and enhances maintainability over the service life of the structure (Fitriansyah & Latief, 2024). Consequently, the deck-on-pile system remains a widely adopted solution for modern port and jetty development in challenging offshore environments.

2.2 Environmental Parameter Assessment

Reliable characterization of the marine environment at the design site is a prerequisite for safe and economical jetty design. The principal environmental parameters requiring quantification are tidal range (defining the variation in water level between the design High Water Level (HWL) and design Low Water Level (LWL)), wave height and period (determining wave loading and freeboard requirements), wind speed and direction distribution (generating wind loads on vessels and structures), current velocity profile (generating hydrodynamic drag on piles and vessel hull), and site bathymetry (determining pile lengths, dredging requirements, and navigation channel geometry) (Triatmodjo, 1996).

Tidal analysis uses the harmonic decomposition of observed tidal records to determine astronomical tide constituents and predict design tidal levels (Abubakar, Mahmud, Tang, Hussaini, & Md Yusuf, 2019). In Indonesian waters, which exhibit predominantly semi-diurnal tidal regimes with significant diurnal inequality, the Highest Astronomical Tide (HAT) and Lowest Astronomical Tide (LAT) define the extreme tidal envelope within which all structural and operational parameters must operate. Wind data for wave hindcasting were obtained from meteorological records, with adjustments applied to convert land-station wind measurements to equivalent open-water conditions using the correction factors adopted by Triatmodjo (1996).

In addition to tidal and wind data processing, the determination of wave characteristics in the study area requires careful consideration of local bathymetry and fetch limitations (Liao and Kaihatu, 2016). Wave hindcasting is typically performed using empirical or semi-empirical models, such as the SMB (Sverdrup-Munk-Bretschneider) method or equivalent numerical approaches, which relate wind speed, fetch length, and storm duration to significant wave height and period. The resulting wave parameters were then statistically analyzed to determine the design wave conditions based on return periods appropriate for marine infrastructure, commonly 25-year or 50-year extremes depending on the project classification (Hanafi, Sudianto, Hamsal, & Hidayat, 2025).

Furthermore, wave transformation processes, such as shoaling, refraction, and breaking, were evaluated as waves propagated toward shallow coastal waters near the jetty location. These transformations significantly influence the nearshore wave height and energy dissipation, which directly affect the structural loading on the deck, piles, and fender systems. Therefore, the accurate integration of tidal levels, wind conditions, and wave transformation effects is essential to ensure reliable and safe marine structural design under combined environmental loading conditions (Wei, Shang, & Zhong, 2023).

2.3 Berthing and Mooring Force Analysis

The forces transmitted to a jetty structure during vessel berthing and mooring operations represent the governing load cases for the structural design of the dolphin and fender systems. The berthing energy (E_B) is computed from the kinetic energy of the approaching vessel, modified by hydrodynamic mass, eccentricity, softness, and berth configuration factors that account for the partial energy absorption by the vessel hull flexibility and surrounding water (Quinn, 1961). The energy that is not absorbed by the vessel is transferred to the fender system and then to the berthing dolphin structure.

Mooring forces arise from the tension in mooring lines restraining the vessel against wind, current, and wave-induced motions (Davidson & Ringwood, 2017). The design mooring forces are calculated from the aerodynamic and hydrodynamic drag forces acting on the moored vessel, resolved into longitudinal and transverse components, and distributed among the mooring lines according to their geometric configuration. Bollard pull forces are specified in accordance with standard design curves relating the bollard capacity to vessel displacement, with the 2,000 DWT design vessel class requiring a 35-ton bollard capacity, as specified by Quinn (1961).

In addition to the primary mooring line forces, environmental load combinations must be considered to capture the most critical loading scenario for a moored vessel. These combinations include the simultaneous actions of wind, current, and wave-induced drift forces, which may act in different directions and produce amplified resultant tensions in individual mooring lines. Dynamic effects due to vessel surge, sway, and yaw motions are also considered using amplification factors, particularly in exposed offshore locations where wave energy is relatively high. The resulting maximum line tensions are then compared with the allowable limits of the mooring line strength, ensuring an adequate factor of safety against failure under extreme environmental conditions.

The distribution of mooring forces is further influenced by the stiffness and elasticity of individual mooring lines, as well as the geometric arrangement of bollards and fairleads on the vessel and jetty structure (Villa-Caro, Carral, Fraguela, López, & Carral, 2018). Lines positioned at smaller angles relative to the vessel centerline typically carry higher loads, necessitating the careful optimization of the mooring layout to achieve a balanced force distribution. In practical design applications, iterative calculations or numerical mooring analysis software are often employed to simulate different loading conditions and ensure system stability. This approach enhances operational safety by minimizing excessive line stress concentrations and reducing the risk of vessel excursions beyond the allowable limits.

2.4 Pile Foundation for Marine Structures

Driven steel pipe piles are the most widely adopted pile type for marine structures in Southeast Asian coastal environments, combining high axial and lateral load capacity, durability against marine corrosion (when adequately coated or cathodically protected), resistance to driving damage, and compatibility with standard marine construction plants (Rubino, Nisticò, Tucci, & Carlone, 2020). The pile bearing capacity in cohesionless and mixed soil profiles is assessed using the SPT-N correlation methods established in Indonesian practice, combining the end bearing capacity (proportional to the SPT-N at the pile tip and pile cross-sectional area) with the skin friction capacity (proportional to the average SPT-N along the pile shaft and pile perimeter area).

A safety factor of 3 was applied to the end bearing and 5 to the skin friction in the service state capacity assessment, following Indonesian geotechnical practice. The pile group behavior must be evaluated when multiple piles act in close proximity, as group efficiency reductions may apply when the center-to-center spacing falls below 2.5 times the pile diameter. The Uniform Building Code (AASHTO) spacing criterion specifies a minimum spacing that ensures that the group efficiency remains acceptable, and the design pile spacing must satisfy this criterion to ensure that the individual pile capacities can be mobilized without group interference (Noman, Abd-Awn, & Abbas, 2019).

The behavior of pile groups must also be considered when multiple piles are installed in close proximity, as interaction effects may reduce the overall group efficiency when the spacing between piles is less than 2.5 times the pile diameter (Mirzaeefard & Hariri-Ardebili, 2024). According to the spacing requirements recommended by the AASHTO and Uniform Building Code, adequate center-to-center spacing is essential to minimize overlapping stress zones in the surrounding soil. Failure to satisfy this criterion may result in a reduced load-carrying capacity owing to group interaction effects. Therefore, proper pile spacing must be maintained to ensure that the individual pile capacities can be fully mobilized without significant reduction caused by group interference. In addition, appropriate spacing improves constructability, reduces installation difficulties, and ensures a more uniform load distribution within the pile foundation system.

2.5 Concrete Structural Design Standards

The structural concrete design for the jetty deck, trestle slab, beam elements, and dolphin caps follows SNI 2847:2013, Indonesia's reinforced concrete design standard based on ACI 318. The key design parameters include a concrete compressive strength f'c = 35 MPa and a reinforcing steel yield strength fy = 390 MPa. The load combinations follow the factored load format: governing combinations include 1.4D + 1.4A (dead load plus current), 1.2D + 0.3E (dead plus seismic), and 1.2D + 1.2A + 1.2B + 1.2M (dead, current, berthing, and mooring), as specified by Triatmodjo (1996). The seismic design follows SNI 03-1726-2002 for the relevant seismic zone applicable to the Batam Archipelago.

In addition to the strength design provisions, serviceability considerations play a crucial role in ensuring the long-term performance of the jetty structure under operational conditions. The deflection limits for beams and slabs are controlled in accordance with the SNI requirements to prevent excessive deformation that may affect operational safety, particularly during berthing and cargo transfer activities. Crack width control is also implemented to enhance durability in aggressive marine environments, where chloride exposure and cyclic wetting-drying conditions can accelerate reinforcement corrosion (Dauji, 2018). Therefore, the minimum reinforcement ratios and spacing requirements are carefully applied to maintain the crack widths within the allowable limits.

Furthermore, durability design is addressed through adequate concrete cover, which is typically increased for marine exposure conditions to protect the reinforcing steel from corrosion (Melchers, 2020). Special attention was given to exposure classification, considering the high salinity and humidity characteristics of the Batam coastal environment. Where necessary, protective measures, such as epoxy-coated reinforcement or additional surface treatments, should be considered to extend the service life. The combined application of strength, serviceability, and durability criteria ensures that the jetty structure satisfies the ultimate limit state requirements and maintains structural integrity and functionality throughout its intended design life under harsh offshore environmental conditions.

3. Methodology

3.1 Data Collection

This study employs primary and secondary data sources. Primary data were collected through direct field investigations comprising topographic surveys of the onshore approach area and nearshore zone, geotechnical soil boring at the proposed pile locations to determine SPT-N profiles and soil stratigraphy, tidal gauge observations to establish local tidal datum, and oceanographic current measurements conducted by BMKG at water depths of 0.2d, 0.6d, and 0.8d during spring tide and neap tide conditions. Bathymetric survey data were provided by PT Majesty Group, which defined the seabed contours within the project area. The secondary data comprised regional wind data from Kepulauan Riau meteorological stations, indicating the dominant February wind direction from north to northeast at speeds of up to 24 knots; wave hindcasting datasets derived from long-term wind records; and vessel particulars for the 2,000 DWT design tanker class obtained from standard Lloyd's Register vessel dimension tables.

3.2 Design Workflow

The design process followed a sequential analytical workflow. Environmental parameter determination establishes design tidal levels, wave heights, wind speeds, and current velocities from the collected field and secondary data. Vessel characterization defines the design vessel's dimensions, displacement, and berthing/mooring force characteristics. Structural configuration selection evaluates the suitability of alternative jetty types against site conditions, resulting in the selection of the pier-type deck-on-pile configuration with berthing and mooring dolphins. Structural analysis uses ETABS v9 finite element software to model a three-dimensional deck-on-pile structural system under all applicable load combinations. The internal forces and moments from the ETABS output form the basis for the reinforced concrete design of all structural elements. The pile capacity was verified against the maximum pile reaction from the structural analysis using SPT-based ultimate capacity calculations with appropriate safety factors. All design results are checked against the requirements of SNI 2847:2013 and SNI 03-1726-2002.

3.3 Load Combination Framework

Structural design employs the following governing load combinations, as proposed by Triatmodjo (1996):

$$Combo\ 1: U = 1.4D + 1.4A \quad (1)$$

$$Combo\ 2: U = 1.2D + 0.3E \quad (2)$$

$$Combo\ 3: U = 1.2D + 1.2A + 1.2B + 1.2M \quad (3)$$

Where D is the dead load (self-weight), A is the current force, E is the equivalent static seismic force, B is the berthing force, and M is the mooring force.

4. Results and Discussion

4.1 Design Vessel Characteristics

The design vessel for this jetty is a 2,000 DWT fuel tanker with the dimensional characteristics listed in Table 1. The 5.0 m draft determines the required minimum water depth at the berth face, which, combined with the required underkeel clearance of 10% of the draft (0.5 m), establishes the minimum dredged or natural seabed depth requirement of 5.5 m below the chart datum at the berthing position.

Table 1. Design vessel particulars — 2,000 DWT Fuel Tanker

Parameter	Value
Displacement (DWT)	2,000 tons
Length Overall (LOA)	77 m
Draft (D)	5.0 m
Beam (B)	12.20 m
Wind-exposed side area	288.4 m²
Berthing velocity	0.15 m/s
Bollard pulls force	35 tons

4.2 Jetty Configuration and Elevation

Site topographic and bathymetric surveys confirmed that the nearshore water depths at Kabil are insufficient to accommodate the 5.0 m design draft without an offshore extension. Therefore, the pier-type (jetty) configuration with deck-on-pile construction was adopted, extending the structure offshore to a location where natural water depths provide adequate draft clearance, thereby minimizing dredging requirements while maintaining structural economy. The trestle approach bridge connects the offshore jetty head to an onshore terminal area. The design deck elevation was determined from the tidal analysis as follows:

$$Elevation = HWL + ½H\_wave + Freeboard \quad (4)$$

$$Elevation = 3.20 + ½\,(0.50) + 1.50 = +5.29\,m\,(Chart\ Datum) \quad (5)$$

Where HWL = High Water Level = 3.20 m, H_wave = design wave height = 0.50 m (from refraction-diffraction analysis), and freeboard = 1.50 m. The resulting elevation of +5.29 m corresponds to the existing Customs (Bea Cukai) jetty elevation at the site, providing a consistent operational interface. Jetty deck length is determined by:

$$Lp = n \times LOA + (n+1) \times 10\% \times LOA \quad (6)$$

$$Lp = 1 \times 77 + 2 \times 0.1 \times 77 = 92.4\,m \approx 92\,m \quad (7)$$

Lp = 1 × 77 + 2 × 0.1 × 77 = 92.4 m ≈ 92 m

For a single-berth layout (n=1), the design jetty length is 92 m, accommodating a 77 m LOA design vessel with adequate bow and stern clearance.

4.3 Environmental and Operational Load Summary

Table 2. Design load summary for 2,000 DWT Tanker Jetty

Load Type	Component	Magnitude
Dead Load	Self-weight of structure	887.97 tons
Live Load	Uniformly distributed	9.20 tons
Seismic Load	Equivalent static	40.59 tons
Berthing Load	Ship impact energy	3.44 t·m
Wind Load (α = 90°)	Transverse (governing)	18.734 tons
Wind Load (α = 0°)	Longitudinal (bow)	7.153 tons
Wind Load (α = 180°)	Longitudinal (stern)	8.515 tons
Current Force	Hydrodynamic	670.27 kg
Mooring Force	Ship line tension	35 tons

Note: Wind loads were calculated for three approach directions. The governing transverse wind load (α = 90°) controls the mooring dolphin design.

Table 2 shows that the dead load (887.97 tons) is the dominant force, followed by significant environmental and operational actions, including the seismic load (40.59 tons), wind loads (up to 18.734 tons in the transverse direction), and mooring force (35 tons). The live load (9.20 tons) is relatively minor compared to the permanent and environmental loads, whereas the berthing impact energy (3.44 t·m) represents the vessel docking effects on the structural components. The hydrodynamic current force (670.27 kg) was comparatively small but was still considered in the stability checks. Overall, the results indicate that gravity loads govern the structural demand, whereas wind, seismic, berthing, and mooring effects critically control the design of specific structural elements and connection details of the jetty system. Mooring dolphin bollard forces were resolved for four mooring line angles: 12.54 tons (α = 21°), 14.24 tons (α = 24°), 24.75 tons (α = 45°), and 35.00 tons (α = 90°). The governing design bollard load is 35 tons (vertical mooring line), which governs the mooring dolphin structural design.

4.4 Structural Design Results

Table 3. Structural dimensions and reinforcement schedule

Element	Dimension	Reinforcement
Jetty deck	Elev. +5.29 m, L = 90 m, W = 200 cm	—
Main beam	600 × 700 mm	Span: 10D23; Support: 12D23
Trestle slab	t = 300 mm	Dir. X: D22–200; Dir. Y: D22–100
Berthing dolphin	12.0 × 3.20 × 2.50 m	D32–150 (As = 120,576 mm²)
Mooring dolphin	3.50 × 3.50 × 2.50 m	D22–100 (As = 37,994 mm²)
Pile cap	3.00 × 3.00 × 2.25 m	—
Steel pipe pile	Ø600 mm, L = 17 m	Qult = 187.17 tons
Fender	Type KVF-400	Deflection 45%, Rf = 13.67 tons
Bollard	35-ton capacity	For 2,000 DWT vessel

Note: Concrete f'c = 35 MPa; Steel fy = 390 MPa (SNI 2847:2013).

Table 3 presents a comprehensive configuration consisting of a 90 m long and 20 m wide jetty deck at elevation +5.29 m, supported by a 600 × 700 mm main beam system with reinforcement of 10D23 at midspan and 12D23 at supports, and a 300 mm thick trestle slab reinforced in two directions. The substructure includes berthing and mooring dolphins, designed as 12.0 × 3.2 × 2.5 m with D32–150 reinforcement (As = 120,576 mm²) and 3.5 × 3.5 × 2.5 m with D22–100 reinforcement (As = 37,994 mm²). The foundation system consisted of a Ø600 mm steel pipe pile with a length of 17 m, achieving an ultimate capacity of 187.17 tons, supported by a 3.0 × 3.0 × 2.25 m pile cap. The marine equipment includes a KVF-400 fender system with 45% deflection and 13.67 tons reaction force, and a 35-ton bollard designed for 2,000 DWT vessel operations. Overall, the configuration demonstrates a balanced integration of structural strength, stability, and operational performance under marine loading conditions.

4.4.1 Main Beam Design

The governing positive moment in the main beam (600 × 700 mm) from the ETABS v9 analysis is Mu = 48,108.63 kg·m. Six D25 longitudinal bars (As = 2,943.75 mm²) were provided, satisfying the minimum reinforcement ratio requirement of SNI 2847:2013 Section 9.6.1.

4.4.2 Trestle Slab Design

The 300 mm trestle slab is designed for a factored uniform load of U = 1.2 × 720 + 1.6 × 100 = 1,024 kg/m². Design moments are:

Mtx = 0.540 × 1,024 × 4.0 = 2,211.84 kg·m/m (X-direction)

Mty = 0.190 × 1,024 × 121 = 23,541.60 kg·m/m (Y-direction)

Required reinforcement in X-direction (d = 270 mm): As = ρ_min × b × d = 0.0115 × 1,000 × 270 = 3,105 mm²/m; D22–200 provides as = 3,799.4 mm²/m > 3,105 mm² ✓. The D22–100 y-direction reinforcement satisfies the higher moment requirement.

4.5 Mooring Dolphin Design

The mooring dolphin (3.5 m × 3.5 m × 2.5 m) is designed to resist both vertical and horizontal environmental and operational loadings. The vertical load was calculated as Q = 36,750 kg, derived from the structural self-weight of the dolphin. The total governing horizontal force acting on the structure was 59.48 tons, consisting of the ship pull (35 tons), wind load (18.734 tons), current force (0.670 tons), and seismic force (5.073 tons). At the critical section (a–a), the resulting design moment was M = 32,156.25 kg·m, obtained from the vertical load distribution over the effective lever arm. For the structural reinforcement design, the minimum reinforcement ratio controls the section because the computed reinforcement requirement is below the minimum value. Using ρmin = 0.004, the required steel area is as = 35,000 mm², whereas the provided reinforcement using D22–100 bars yields as = 37,994 mm², which satisfies the design requirement (OK). Overall, the mooring dolphin section is structurally adequate to resist the combined vertical, horizontal, and moment effects under the governing load conditions.

4.6 Berthing Dolphin Design

The berthing dolphin (12.0 × 3.2 × 2.5 m) is designed to resist significant vertical and horizontal loads induced by vessel berthing operations. The self-weight of the structure was calculated as 72,000 kg/m, resulting in a governing bending moment at section (a–a) of 216,000 kg·m, based on the effective lever arm of one-quarter of the dolphin length. For structural safety, a minimum reinforcement ratio of ρmin = 0.004 was adopted, yielding a required steel area of as = 120,000 mm². The provided reinforcement using D32–150 bars resulted in as = 120,576 mm², which satisfied the design requirement (OK). In addition, the dolphin is designed to accommodate a KVF-400 fender system with a berthing energy absorption capacity of 3.44 t·m, ensuring that impact forces from vessel docking are safely dissipated. The structural system is supported by a pile group consisting of 10 vertical Type A piles and 4 inclined Type B steel pipe piles, which collectively resist the combined vertical loads, lateral berthing forces, wind, current, and seismic effects, ensuring the overall stability and performance of the berthing structure under operational conditions.

4.7 Pile Foundation Capacity

Table 4. Steel pipe pile bearing capacity summary (Ø600 mm, L = 17 m)

Capacity Component	Formula	Value (tons)	Status
Material strength (Qa)	Ap × (0.58fy)	63.92	OK
End bearing capacity	(40N × Ap)/3	150.72	OK
Skin friction capacity	(N′ × As/5)/5	36.45	OK
Ultimate capacity (Qult)	End + Friction	187.17	OK
Max. pile load (Pmax)	ETABS analysis	73.50	< 187.17 ✓

Note: SPT N-average ($\bar{N}$) = 28.45; Ap = 2,826 cm²; As = 3,203 cm² (shaft area). The safety factors were F = 3 (end bearing) and F = 5 (friction).

Table 4 shows that all the design components satisfied the required safety criteria. The material strength contribution was 63.92 tons, the end bearing capacity was 150.72 tons, and the skin friction capacity was 36.45 tons, resulting in a total ultimate pile capacity (Qult) of 187.17 tons, which is classified as adequate (OK). From the structural analysis using ETABS, the maximum applied pile load was 73.50 tons, which was significantly lower than the ultimate capacity, confirming a safe design condition with a satisfactory safety margin. Overall, the results demonstrate that the pile foundation system is structurally stable and capable of safely resisting the applied loads under the governing design conditions. The ultimate pile capacity is expressed as

$$Q_{ult} = (40N \times A_p)/3 + (\bar{N} \times A_s/5)/5$$
$$Q_{ult} = 150.72 + 36.45 = 187.17 \text{ tons}$$

The structural analysis indicated that the maximum pile load of 73.50 t was significantly lower than the ultimate pile capacity of 187.17 t, confirming that the pile foundation system was adequately designed with a safety factor exceeding 2.5, thus satisfying the required structural safety criteria. In addition, the pile group spacing was evaluated using the AASHTO/UBC criterion to ensure group efficiency and avoid the interaction effects between adjacent piles. The maximum allowable spacing was calculated as $S \leq 1.884$ m based on the pile diameter, group configuration, and spacing formula parameters. The adopted pile spacing of $S = 1.7$ m satisfies this requirement ($S < 1.884$ m ✓), indicating that the pile group maintains an acceptable efficiency without a significant reduction in capacity owing to group interaction. Overall, both capacity and spacing checks confirmed that the pile foundation system was structurally safe, stable, and efficient under the governing design conditions.

4.8 Discussion
The structural design confirmed that the deck-on-pile configuration is technically and economically appropriate for the Kabil site conditions. The extension of the jetty offshore to achieve adequate draft clearance without dredging is justified by the shallow nearshore bathymetry, and the resulting structural dimensions are consistent with comparable jetty designs for vessels of this displacement class in Southeast Asian port environments (Morris, 2017; Negi, Kromanis, Doree, & Wijnberg, 2024).

The governing structural challenge is the dolphin design, where the combination of mooring line forces, wind loads on the moored vessel, and current drag generates substantial horizontal forces (59.47 tons in total) that must be transmitted to the pile foundation through a relatively compact pile cap. The provision of inclined Type B piles alongside vertical Type A piles in the berthing dolphin pile group is an effective design strategy for resisting horizontal forces without requiring impractically large pile cross-sections, which is consistent with the established design practices for marine berthing structures (Quinn, 1961). The pile capacity analysis confirmed that steel pipe piles with a Ø600 mm diameter driven to a −17 m depth achieved a satisfactory ultimate capacity with a safety factor exceeding 2.5. The SPT-based capacity assessment, although standard in Indonesian practice, introduces uncertainties associated with the variability of SPT measurements in mixed coastal soil profiles. A static load test on at least one production pile is recommended during construction to verify the design capacity assumption.

5. Conclusions
5.1 Conclusion
This study presents the complete structural design of a 2,000 DWT tanker jetty at Kabil, Batam Island, covering jetty configuration selection, environmental load assessment, reinforced concrete structural design, and steel pipe pile foundation analysis, all of which were verified using ETABS v9. The results indicate that the pier-type deck-on-pile configuration is the most suitable and economical solution for the site conditions, effectively eliminating the need for extensive dredging works. The designed jetty elevation of +5.29 m above the chart datum, based on the HWL (3.20 m), wave height contribution (0.25 m), and freeboard (1.50 m), ensures adequate operational clearance. All reinforced concrete elements, including the 600 × 700 mm beams, 300 mm trestle slab, berthing dolphin (12.0 × 3.2 × 2.5 m), and mooring dolphin (3.5 × 3.5 × 2.5 m), comply with the SNI 2847:2013 strength requirements.

The Ø600 mm steel pipe piles driven to −17 m achieved an ultimate capacity of 187.17 tons against a maximum demand of 73.50 tons, providing a safety factor greater than 2.5, while the pile spacing satisfied the AASHTO/UBC efficiency criteria. Additionally, the KVF-400 fender system and 35-ton bollard ensure adequate berthing energy absorption and mooring capacity for safe 2,000 DWT vessel operation.

5.2 Research Limitations
This study has four limitations. First, the structural design is based on the equivalent static seismic analysis method (SNI 03-1726-2002); a dynamic response spectrum or time history analysis may be warranted for final design verification given the seismically active geological setting of the Batam Archipelago. Second, the soil investigation data are based on a limited number of bore holes; additional borings along the full jetty alignment would reduce geotechnical uncertainty, particularly for pile length determination in areas with variable soil stratification. Third, this study did not include a static load test program for pile verification; field load testing during construction is strongly recommended to confirm design capacity assumptions. Fourth, durability design aspects, including concrete cover specifications for marine exposure, cathodic protection system design for steel piles, and maintenance interval planning, are not addressed within the scope of this paper.

5.3 Suggestions and Directions for Future Research
Three research directions are recommended. First, a comparative structural performance study examining alternative pile configurations, including prestressed concrete piles and steel H-section piles, for the same site conditions would provide quantitative cost-performance data to support future pile type selection decisions for comparable projects in Batam's offshore industrial zone. Second, a dynamic analysis of the jetty-dolphin structural system under time-varying wave loading would provide refined estimates of fatigue-sensitive structural details, particularly connection nodes between deck beams and pile caps that are subjected to cyclic wave-induced displacement histories. Third, a lifecycle cost analysis incorporating the initial construction cost, maintenance frequency and cost, and service disruption probability would provide the economic basis for comparing the deck-on-pile configuration adopted here with alternative structural systems, including gravity foundation caissons and prefabricated modular berth units, for future tanker terminal development in the Kabil port area.

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