Effects of Pile Configuration on The Behaviour of Jetty Structure Subject to Lateral Loads

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Abstract. Piles are structural elements which play an important role to carry loads and transfer them to the ground. In a jetty structure, the critical lateral loads supported by piles are mostly from Liquid Natural Gas (LNG) vessels. This research investigates various pile configuration such as pile diameter (40 cm, 60 cm, and 80 cm), distance between pile (2.5 m and 5 m), and the slope of the pile (straight pile and sloping pile with the ratio 1:8). A series of analysis has been conducted using SAP 2000 program. The analysis results show that a smaller pile deflection can be obtained if a large diameter pile is used, distance between piles is 2.5 m, and the type of piles being installed is a sloping pile.

Keyword: Pile, Lateral Loads, Liquified Natural Gas (LNG), Deflection, SAP2000

1. Introduction
Jetty is one of the pier structures generally constructed jutting into the sea at a harbour. The jetty serves as a connection between the land and the waterway as a special facility for loading and unloading oil and gas as well as preventing silting on the underside of the ship due to sediment accumulation carried by sea currents to the coast [1]. There are several things that need to be considered in the construction of a jetty structure [2], such as the construction of a tressel structure, where this structure serves as the main road or the access from the pier to the mainland and the construction of a main jetty that serves as a place to lean the ship [3, 4, 5] and is planned to be able to serve Liquified Natural Gas (LNG) vessel. Jetty structure design adopts pile foundation to support the structure of the pier and the load caused by the vessel [6, 7]. The pile configuration on the jetty structure is very important particularly the size of the pile cross section, the distance between the piles, and the pile structure modeling for the construction of the pier structure [8, 9]. The effective pile configuration is required to reduce pile deflection [10, 11, 12]. Numerical model has widely used in planning to simulate the wave forces affecting the marine structure [13, 14].

This research investigates the stability of the pile structure on the jetty with various configuration against the lateral load of Liquified Natural Gas (LNG) vessels. The lateral load that occurs on the pier will affect the deflection and movement of the piles at the jetty structure. Moreover, the characteristics of the pile deflection are also examined on the variation of the pile configuration by performing the finite element model of the jetty.
structure using the SAP2000 program. From the analysis, the theoretical equation is developed which provide the relationship between the parameters of the allowable piles deflection and the results of the pile deflection analysis on the diameter of the pile and the distance between the piles. The results can be used as a reference for the planning of the jetty structure with the limitations of the distance between pile are 2.5 m and 5 m due to the maximum lateral load of Liquified Natural Gas (LNG) vessels.

2. Methodology
In this study, SAP2000 program is utilized to model the structure. Figure 1 and Figure 2 show the model of jetty structure using slope pile and straight pile, respectively. The structure is subjected to the maximum load based on the specification as shown in Table 1. A series of analysis are performed under different scenarios as shown Table 2. The study investigates the effect of pile diameter and configuration on the behaviour of the jetty structure subjected to the maximum load.

| Table 1 | Liquefied Natural Gas (LNG) Vessel Specification |
|---------|--------------------------------------------------|
| Description | Liquified Natural Gas (Ton) |
| DWT | 75000 |
| LOA | 288 |
| Beam | 49 |
| Draft | 11.5 |
| Freeboard | 7 |
| LPP | 274 |

| Table 2 | Variation of Jetty Model Structure Pile Configuration |
|---------|-----------------------------------------------------|
| Modeling of Pile Structure | Distance between Piles (m) | Piles Diameter (cm) |
| Slope Pile (1:8) | 2.5 | 40 |
| Straight Pile | | 60 |
|  | | 80 |
| Slope Pile (1:8) | 5 | 40 |
| Straight Pile | | 60 |
|  | | 80 |

Figure 1: Modeling of The Jetty Structure Using A Sloped Pile Structure (1: 8)  
Figure 2: Modeling of The Jetty Structure Using A Straight Pile Structure
3. Result and Discussion

3.1. Analysis of Lateral Force of Liquified Natural Gas (LNG) Vessel

Lateral force calculation is obtained from the source of the load received by the pole structure by using the equation of the ship's impact energy when the ship hits the pier with the slope angle of the 10° vessel to the center of the ship. In this calculation, the maximum load from the specifications of the Liquefied Natural Gas (LNG) vessel is used as shown in Table 3.

Table 3: Lateral Force Analysis ($F_{berthing}$) Liquified Natural Gas (LNG) Vessel

| Description                                                      | Piles Structure |
|------------------------------------------------------------------|-----------------|
|                                                                 | D40 cm | D60 cm | D80 cm |
| Dead Weight Tonnage (ton)                                        | 75000   | 75000  | 75000  |
| Maximum Mass Displacement($\Delta m$)                            | 117000  | 117000 | 117000 |
| The length of the vessel's surface line ($Loa$ (m))              | 288     | 288    | 288    |
| The length of the vessel’s parallel to the water ($Lpp$ (m))     | 274     | 274    | 274    |
| Width ($B$ (m))                                                  | 49      | 49     | 49     |
| Draft ($T$ (m))                                                  | 11,5    | 11,5   | 11,5   |
| Coefficient of block ($Cb$)                                      | 0,74    | 0,74   | 0,74   |
| Displacement Tonnage($DT$ (ton))                                 | 98301,14| 98301,14| 98301,14|
| Coefficient of mass ($Cm$)                                       | 1,99    | 1,99   | 1,99   |
| Coefficient of eccentricity ($Ce$)                               | 0,48    | 0,48   | 0,48   |
| Coefficient of hardness ($Cs$)                                   | 1       | 1      | 1      |
| Coefficient of berthing ($Cc$)                                   | 1       | 1      | 1      |
| Energy of berthing ($E_{berthing}$ (kNm))                        | 1173,2  | 1173,2 | 1173,2 |
| Energy of absorbed ($Ef$ (kNm))                                  | 586,86  | 586,86 | 586,86 |
| Berthing Force ($F_{berthing}$ (kN))                             | 4915,05 | 4915,05| 4915,05|

3.2. Analysis of The Moment Ultimate of Pile

The lateral load generated by Liquified Natural Gas (LNG) vessels is designed to be supported by the structure of the pile contained in the pier structure. The parameters that affect the structure of the pile due to the lateral load of vessel are the stiffness of the pile structure, and the cross-sections of the pile.

The types of piles used in this study are piles with spun pile types and diameter of pile are 40 cm, 60 cm, and 80 cm. In addition, the quality of concrete pile is K-500. The results of the momen ultimate of the pile that obtained for the configuration of the pile diameter are 40 cm, 60 cm, and 80 cm are presented in Table 4.
Table 4 Moment Ultimate Analysis of Pile

| Description                        | D40 cm | D60 cm | D80 cm |
|------------------------------------|--------|--------|--------|
| Eccentricity of The Pile (m³)      | 0,0035 | 0,011  | 0,024  |
| Modulus of Elasticity of Concrete (kN/m³) | 957462,79 | 957462,79 | 957462,79 |
| Modulus of Cohesive Soil (n₀) (kN/m³) | 600    | 600    | 600    |
| Rigidity of Pile (m)               | 1,024  | 1,39   | 1,73   |
| Type of Pile (Lp≥4T)               | 19,51≥4(Unrigid pile) | 14,38≥4(Unrigid pile) | 11,56≥4(Unrigid pile) |
| Moment Ultimate of Pile (kNm)      | 87,15  | 273,9  | 597,6  |

3.3. Allowable Ultimate Lateral Force of Pile

The empirical Broms method is adopted to determine the value of the ultimate lateral force of the allowable pile positions under different pile diameters. The calculation is based on the Standard Pile Design and Construction Practice, for soft soil types, the position of pile (Zf) is 1.5 m. The results of the calculation of the allowable ultimate lateral force of pile based on the pile position obtained for the configuration of the pile diameter of 40 cm, 60 cm, and 80 cm are presented in Table 5.

Table 5 Allowable Ultimate Lateral Force of Pile Analysis

| Description                                      | D40 cm | D60 cm | D80 cm |
|--------------------------------------------------|--------|--------|--------|
| Eccentricity of Lateral Load (e) (m)             | 12     | 12     | 12     |
| Ultimate Lateral Force of Width of Pile (Hu) (kN/m) | 12,9   | 40,58  | 88,53  |
| Ultimate Lateral Force of Pile (Hu) (kN/m)       | 5,16   | 24,35  | 70,83  |
| Allowable of Ultimate Lateral Force (Hₚall) (kN) | 2,58   | 12,18  | 35,41  |

3.4. The Result of Allowable of Pile Deflection

Deflection for fixed headed piles is calculated using the formula based on Standard Pile Design and Construction Practice for piles with a diameter of 40 cm, 60 cm and 80 cm. The results of the calculation of the allowable deflection of the pile for configuration of pile diameter of 40 cm, 60 cm, and 80 cm are shown in Table 6:

Table 6 Allowable of Pile Deflection

| Description                                      | D40 cm | D60 cm | D80 cm |
|--------------------------------------------------|--------|--------|--------|
| Eccentricity of Lateral Load (e) (m)             | 12     | 12     | 12     |
| Value of Pile Position (Zr) (m)                  | 1,5    | 1,5    | 1,5    |
| Moment of Inertia of Pile (I) (m⁴)               | 0,0007 | 0,0033 | 0,0096 |
Allowable of Lateral Force (H_{all}) (kN) | 2.58 | 12.18 | 35.08
---|---|---|---
Allowable of Pile Deflection (δ) (cm) | 70.8 | 79.04 | 78.98

3.5. The Result of Numerical Analysis using SAP2000 Program

After loading and loading combinations are obtained and input to 3D pier structure modeling using the SAP2000 program, Table 7 shows the results of deflection analysis obtained from the SAP2000 program for configuration of pile diameter 40 cm, 60 cm, and 80 cm with distance between piles 2.5 m and 5 m.

Table 7 The Result of Deflection Analysis with Pile Spacing 2.5 m

| Diameter (cm) | Allowable of Pile Deflection (δ_{allowable}) (cm) | Deflection Result from SAP2000 Program (δ) (cm) |
|---------------|---------------------------------|----------------------------------|
|               | Sloped Pile (1:8) | Straight Pile |
| 40            | 70.8 | 48.2 | 215.6 |
| 60            | 79.04 | 17.4 | 50 |
| 80            | 78.25 | 6.13 | 13.62 |

Table 8 The Result of Deflection Analysis with Pile Spacing 5 m

| Diameter (cm) | Allowable of Pile Deflection (δ_{allowable}) (cm) | Deflection Result from SAP2000 Program (δ) (cm) |
|---------------|---------------------------------|----------------------------------|
|               | Sloped Pile (1:8) | Straight Pile |
| 40            | 70.8 | 63.15 | 326.83 |
| 60            | 79.04 | 21.86 | 73.57 |
| 80            | 78.25 | 7.28 | 18.7 |

From the results obtained in Table 7 and Table 8, the following is a graph of the relationship between the deflection of the piles on the diameter of the piles in the pile configuration diameter 40 cm, 60 cm, and 80 cm for the distance between the piles 2.5 m and 5 m using the sloped pile (1:8) and straight pile:

Figure 3 The Relationship Between The Deflection of Piles Against Piles Diameter (LNG Vessel 75000 DWT)
The graph in Figure 3 shows that the deflection results caused by LNG vessels on variations in diameter of pile 40 cm, 60 cm, and 80 cm and variations in distance between poles 2.5 m and 5 m, with modeling of pile structure using pile combinations with sloped pile (1: 8) is smaller than using a pile structure model using a straight pile.

### 3.6. Relation Between the Parameter of Pile Deflection (δ), Allowable of Pile Deflection (δ allowable), Pile Diameter (D), and Pile Spacing (S)

From the results of the pile deflection analysis obtained in Table 6 and Table 7, then the results can be re-analyzed to find the value of the theoretical development equation of the relationship between deflection parameters of the pile to the pole diameter and the distance between the piles caused by the LNG vessel load of 75000 DWT. To determine the theoretical development equation of the relationship between pile deflection (δ), allowable of pile deflection (δ allowable), pile diameter (D), and pile spacing (S), need a cross-section ratio of jetty pile structure (D / S) and stability ratio jetty structure (δ allowable / δ).

The cross-section jetty pile structure ratio (D/S) is the ratio between the effect of pile inertia diameter (D) on the distance between the piles (S). The greater the cross-sectional ratio of the jetty structure, the more rigid the pile structure is. This is influenced by the larger the diameter of the pile used and makes the moment of inertia more enlarged resulting in a more rigid and stable pile structure. Conversely, the smaller the ratio of the jetty pile structure cross section, the pile is easy to flex and results in a deformation of the mast structure. This is influenced by the smaller the diameter of the pile used and makes the moment of inertia also smaller and causes the pile structure to be easily deformed (deflected) and unstable.

In addition to the cross-section ratio of the jetty pile structure (D/S), the stability ratio of the jetty structure (δ allowable / δ) is also needed to determine whether the jetty structure is stable or not depends on the large or small cross-sectional ratio of the jetty (D/S) pile structure.

The jetty structure is declared stable if the stability ratio of the jetty structure is greater or equal to 1 (δ allowable / δ ≥ 1).

### Table 9 The Result of The Relation of Pile Deflection (δ), Allowable Of Pile Deflection (δ allowable), Pile Diameter (D), And Pile Spacing (S)

| Description                        | D/S | Sloped Pile (1:8) | Straight Pile | δ allowable / δ | δ allowable / δ |
|------------------------------------|-----|-------------------|---------------|-----------------|-----------------|
| Jetty modelling with pile spacing 2,5 m | 0.16 | 1.46             | 0.32          |                 |                 |
|                                     | 0.24 | 4.54             | 1.58          |                 |                 |
|                                     | 0.32 | 12.76            | 5.74          |                 |                 |
| Jetty modelling with pile spacing 5 m | 0.08 | 1.12             | 0.21          |                 |                 |
|                                     | 0.12 | 3.61             | 1.07          |                 |                 |
|                                     | 0.16 | 10.74            | 4.18          |                 |                 |

From the results of the analysis in Table 9, it can be developed into a theoretical development equation for the jetty pile structure ratio (D/S) to the stability ratio of the jetty structure (δ allowable / δ), as follows:

### Table 10 The Result of Theoretical Development Equations

| Description                        | PersamaanPengembanganTeoritis |
|------------------------------------|-------------------------------|
| Jetty modelling using sloped pile (1:8) (2.5 m ≤ S ≤ 5 m) | \( \frac{D}{S} = \frac{0.059 \times \ln(\frac{\delta_{\text{allowable}}}{\delta}) + 0.107}{S} \) |

6
Jetty modelling using straight pile \((2.5 \text{ m} \leq S \leq 5 \text{ m})\)

\[
\frac{D}{S} = \left(0.0413 + \ln \left(\frac{\delta_{\text{allowable}}}{\delta}\right)\right) + 0.174
\]

**Figure 4** Result of Theoretical Development with The Relations of Cross-Section Ratio of Jetty Pile Structure (D/S) and Stability Ratio Jetty Structure \((\delta_{\text{allowable}}/\delta)\) using Sloped Pile (1:8)

**Figure 5** Result of Theoretical Development with The Relations of Cross-Section Ratio of Jetty Pile Structure (D/S) and Stability Ratio Jetty Structure \((\delta_{\text{allowable}}/\delta)\) using Straight Pile

The results of these theoretical development equations can be developed into graphical forms based on the analysis results from Table 10, as seen in Figure 4 and 5. The graph in Figure 4 and Figure 5 shows the results of the theoretical study of the equations in Table 10 with the parameters used, namely pile deflection parameters, allowable of pile deflection, pile diameter, and pile spacing. The lines contained in the graph of Figure 4 and Figure 5 can be used as a reference for planning the demaga structure, either modeling piles using sloped pile (1:8) or modeling piles using straight pile.

This equation can be used, and the structure is stated to be stable to be planned if the \(\delta_{\text{allowable}}/\delta \geq 1\), if \(\delta_{\text{allowable}}/\delta < 1\) then the structure planning fails so that it needs re-planning for the pile structure used. The usage requirements of the chart are only used for pile spacing with 2.5 m and 5 m and pile diameter with 40 cm to 80 cm, with the maximum load of ships used in liquified natural gas (LNG) vessels is 75,000 DWT.

**4. Conclusion and Suggestions**

Based on the results of this study, the following conclusions can be made

1. It can be concluded that the greater distance between the pile, the smaller deflection value of the pile. This can be confirmed by the graph of the relationship between the
1. The stability parameters of the jetty structure (δ_{allowable}/δ) to the cross section of the jetty pole structure (D/S).

2. The results of theoretical development can be used to obtain one of the values of the pile configuration parameters and can be used as a reference for jetty structure planning for the maximum load of LNG vessel types with a weight of 75000 DWT. However, the limit for the allowable distance between piles for the use of the equation is 2.5 m and 5 m. The limits for the diameter of the pile allowed for the use of the above equation is 40 cm to 80 cm.

3. The structure is considered to be stable when δ_{allowable}/δ ≥ 1. In contrast, when δ_{allowable}/δ < 1 then the structural design fails and requires a re-modeling of the dock structure for the strengthening of the pier pile structure.

5. References

[1] Chenna R, Ramancharia P K, Singh A P, Rastogi B K 2017 Vulnerability Assessment of Marine Structure: A Case Study on Jetty International Journal of Earth Sciences and Engineering 10(02): 191-199

[2] PIANC 2014 Harbour Approach Channels Design Guidelines. Belgique.

[3] Paulaukas, V. (2016). Ship and Quay Wall Mooring System Capability Evaluation. Transportation Research Procedia, 123-132.

[4] Badan Standardisasi Nasional 2013 SNI 03-2847-2013 Persyaratan Beton Struktural untuk Bangunan Gedung. Jakarta: BSN.

[5] Institute of Japan. (2002). Technical Standards and Comentaries For Port and Harbour Facilities in Japan. Japan: Japan Ports and Harbour Association.

[6] Nishimura, S., Takahashi, H., & Morikawa, Y. (2012). Observation Of Dynamic and Non-Dynamic Interactions Between a Quay Wall and Partially Stabilised Backfill. The Japanese Geotechnical Society, 81-98.

[7] Padmavathi, V., Saibaba Reddy, E., & R. Madhav, M. (2008). Behaviour of Laterally Laoaded Rigid Piles in Cohesive Soils Based on Kinematic Approach. Lowland Technology International, 27-41.

[8] Parung, H., Suprapti, A., & Pranata P. A., D. (n.d.). Perencanaan Dermaga Pelabuhan Peti Kemas Maloy di Kutai Timur. Jurnal Penelitian Teknik Sipil.

[9] Seo, M., Im, J.-C., Kim, C., & Yoo, J.-W. 2016 Study on the applicability of a retaining wall using batter piles in clay. NRC Reasearch Press.

[10] Tomlinson, M., & Woodward, J. 2008 Pile Design and Construction Practice. USA and Canada: Taylor & Francis.

[11] Sitepu, T. A. (2014). Analisis Konfigurasi Pondasi Tiang Pancang Kernel Jetty Terhadap Gaya Lateral Pada Pembangunan Jetty Pulau Laut. Jurnal Teknik Sipil dan Lingkungan, 245-253. (in bahasa)

[12] Fan-ren, L., Ji-ming, Y., & Yao-hua, J. 2011 Study on proportional relationship of lateral bearing capacity of batter pile by mode experiments. Procedia Engineering, 8-13.

[13] Setyandito O, Yuwono N, Nizam, Sjarifudin F U, Mitchell, Saragih J F B 2018 Hydrodynamic flow characteristics of tsunami waves impact on bearing wall layout IOP Conferences Series: Earth and Environmental Science 195.012016

[14] Masria A, Negm a M, Iskander M Saavedra O 2013 Numerical simulation of constructing jetties to stabilize rosetta inlet, Egypt Proceeding Conference: 17th International Water Technology Conference