Eduvest – Journal of Universal Studies
Volume 5 Number 6, June, 2025
p- ISSN 2775-3735- e-ISSN 2775-3727

Analysis of Wharf Strengthening Due to Dredging

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ABSTRACT

This study investigates the structural implications of dredging activities on steel piles and associated railway infrastructure. Specifically, the dredging process, which extended to a depth of 12 meters, effectively reduced the embedded length of the existing steel piles to 8 meters, thereby compromising their load-bearing capacity. Structural modeling and analysis revealed that the reduced pile embedment may lead to insufficient support under operational loads, raising concerns about potential failure and non-compliance with safety standards. As a result, reinforcement measures were implemented, including strengthening the pile heads and installing additional steel piles around the existing foundation. The analysis also assessed the structural performance of key railway components, particularly beams LB1 and LB2, which were found to adequately support the operational QCC load. However, further investigation is recommended for other structural elements to ensure overall system integrity. To maintain safety and performance standards, the study highlights the necessity of re-verifying soil properties post-dredging, performing supplementary structural analyses where required, and strictly adhering to safe operational protocols during railway use. Additionally, a thorough review of beam and plate design specifications is advised to confirm compliance with current structural codes. These findings underscore the importance of integrating geotechnical and structural evaluations in infrastructure projects involving dredging to mitigate safety risks and support sustainable infrastructure management.

KEYWORDS *Dredging, Structural Reinforcement, Safety Evaluation*

INTRODUCTION

The port is a place of international trade activities and a center of economic activity (Forte & Botelho, 2021; Mundaca et al., 2021; Nurrachman & Marjanah, 2023; Pittiglio, 2023; Putri & Yuliani, 2023). In line with the efforts of the central and regional governments for economic development, the port continues to improve itself and continuously equips itself with various facilities and infrastructure that are able to support the acceleration and smooth operation of ship and cargo service activities (Chen et al., 2024; Sandirasegaran & Manap, 2016).

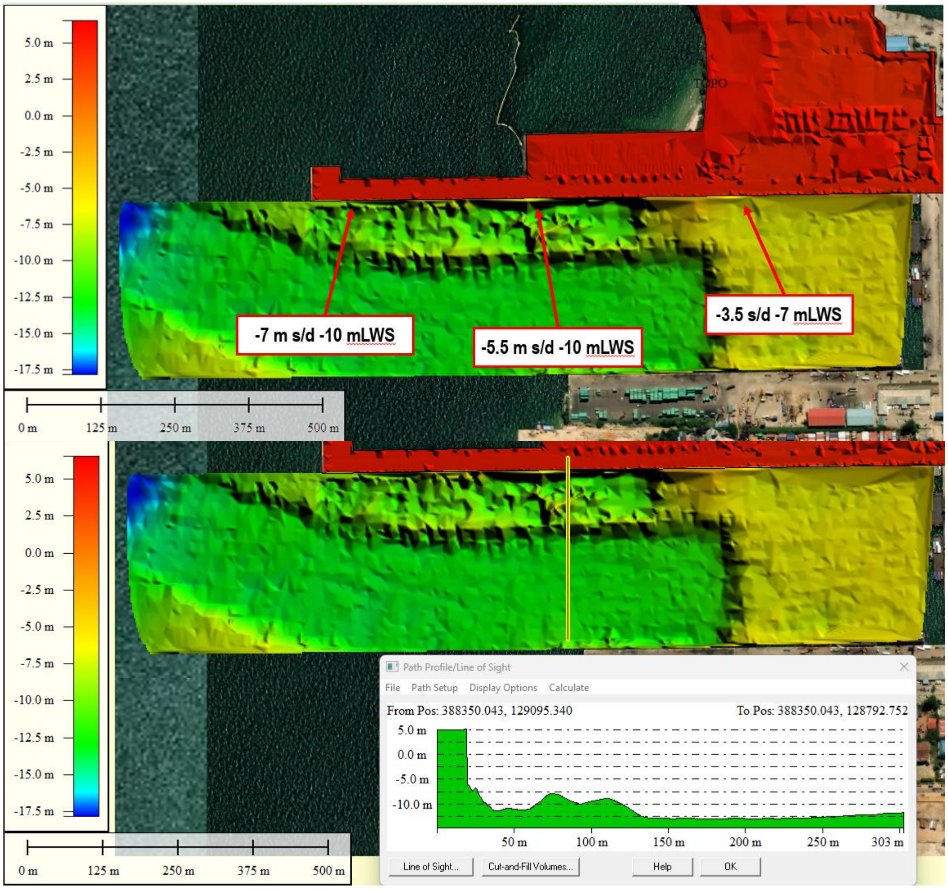
One of the requirements for port development is to have a calm port pool and a relatively deeper water depth. Since the location of the port plan is situated in waters near the coast, it is necessary to increase the depth of the water in the port pool by dredging so that ships can carry out loading and unloading activities in the port. The bottom of the harbor pond will be dredged until it reaches a layer of hard soil/bedrock. Dredging is the process of altering the shape of the water bed to reach the desired depth and width, and/or removing the water bed material for specific purposes (PP No. 5 of 2010).

A pier is a port building used to dock and moor ships that load and unload goods and board and unload passengers (Nilasari & Kamaludin, 2016). XYZ Pier, located on the island of Sumatra, is one of the old piers that is still actively operating and functions as a pier for containers and general cargo. This pier consists of two main segments, namely segment 1 measuring 184 x 35 m² and segment 2 measuring 181 x 35 m², with a deck on pile structure type or a staked pier. The elevation of the pier floor is at a height of +4.50 m from the *Low Water Surface* (LWS), with the planned depth of the waters around the pier being -12.00 m

LWS. The planned life of this pier building is 50 years (Bandari & Sadhukhan, 2021; Czuba et al., 2019; Ventura et al., 2023).

Due to the development of the use of containers, the size of the ships used is getting larger. To increase the productivity of loading and unloading containers and utilize existing construction, deepening or dredging the berth pond is needed. Based on the regulations, the seabed depth requirement is 1.1 to 1.2 ship drafts, so the seabed requirement is 12.8 m to 14 m. In addition, based on the results of topographical, bathymetric, and tidal surveys, there are several areas (pier edges) where shallow areas exist. The type of material dredged is silt soil and very dense sand with a tax return value of 20 to >60.

This dredging can cause steel piles to no longer tread on the original soil (*sea bed*), potentially reducing the stability of the structure. This is very important because reducing the strength of the pile can have a negative impact on the safety and service life of the pier. If the steel pile hangs, then the load received by the pile cannot be transferred properly to the ground, thus increasing the risk of collapse. According to Masagala, Bhaskara, and Setiawan (2021), the evaluation of the existing pier building structure is one of the most important activities. In addition to finding out the reliability and strength of the existing pier structure against the operational load, it is also important to determine how much the maximum pool depth can be achieved if dredging is carried out in front of the pier and what special treatment (reinforcement) is needed if the depth of the pond exceeds the maximum pool depth that can be achieved.



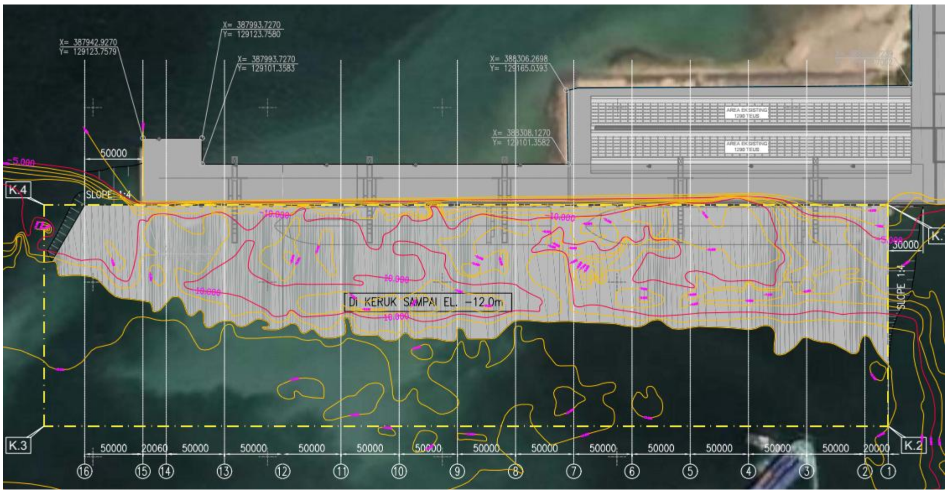


Figure 1. Dredging Layout on XYZ Pier
Source: Secondary Data (2024)

In addition, there is a plan to operate a Rail Mounted Quay Crane (QCC), a dock crane that moves on rails on the *deck-on-pile dock* segment. To operationalize the QCC, it is necessary to re-evaluate the existing pier structure. This evaluation aims to ensure the strength and ability of the pier in withstanding the loads that will be applied, especially the operational load of the QCC. If the result shows that the pier cannot withstand the operational load of the QCC, it will be necessary to strengthen the pier for the safety and security of its users.

A previous study by Sitorus, Widyastuti, and Fuddoly (2023) focused on planning the repair and reinforcement of the north side of a general cargo pier at PT Pupuk Kaltim using Eurocode standards and international references such as OCDI 2009 and BS 6349. It included dredging the dock to 7.48 *mLWS* and designing new structural elements such as floor slabs, beams, and fender pile caps without disrupting loading and unloading activities. Meanwhile, research by Anisadila, Widhiarto, and Fatmawati (2023) replanned pier reinforcement at Berlian Pier in Surabaya by analyzing the load-bearing capacity of pile foundations with various diameters using the Meyerhof method based on N-SPT data. The study concluded that 1.0 m diameter, 32 m long piles were optimal, both in terms of capacity and allowable settlement limits. While both studies contribute significantly to the planning and reinforcement of pier structures, they do not specifically address the structural impacts of deep dredging to -12 meters on existing *deck-on-pile* structures, particularly under the additional operational load of heavy equipment like a Rail Mounted Quay Crane (QCC).

The objectives of this study are as follows: (1) Conducting an analysis of the strength of the existing pier pile structure in bearing the actual load after dredging and the plan to use the rail crane (QCC) on the *deck-on-pile* segment. (2) Providing recommendations for strengthening the steel pile foundation structure of the existing pier due to dredging to a depth of -12m. (3) Providing recommendations for the necessary reinforcement design for the *deck-on-pile* pier so that it is structurally able to withstand the operational load of the rail crane (QCC) that will operate on the pier.

The benefits of this study are as follows: (1) Providing a comprehensive evaluation of the structural condition of the existing pier after dredging and the plan for the use of rail cranes (QCC), ensuring the safety and reliability of pier operations. (2) Producing a suitable reinforcement design for the *deck-on-pile* dock, so that the dock can safely and efficiently accommodate the new operational load of the rail crane (QCC). (3) Providing recommendations for strengthening the existing pier structure necessary to overcome the impact of dredging to a depth of -12 meters, so that the structural integrity of the pier can be maintained. (4) Increasing the capacity and ability of the dock to serve container loading and unloading activities more efficiently and safely, in line with the development of new technology and equipment used. (5) Serving as a reference and source of information for future research or similar projects, especially related to the evaluation and strengthening of port pier structures.

METHOD

This research was carried out on the object of the pier structure located on *Batam Island*. The main purpose of this study is to evaluate and re-analyze the existing condition of the pier. This is motivated by the existence of a dredging work plan in the area around the pier and a plan to use a Quayside Container Crane (QCC) in the *deck-on-pile* type dock segment. This analysis was carried out to ensure that the pier structure is still able to operate safely after dredging work and the increased operational load from the QCC.

Some of the preparatory activities are as follows: (1) Literature study of the planning and evaluation of the pier structure to determine the outline of the evaluation process as a reference. (2) Determining the need for data to be used in evaluating the existing condition of the pier, such as structural data, soil data, environmental data, and operational data. (3) Collecting data that will be used in the evaluation process of existing piers, including preliminary design drawings, structural condition inspection reports, soil investigation data, wind and wave data, and operational load data.

In the process of evaluating and strengthening the existing pier, the secondary data method is used, namely using data from related agencies in accordance with the project plan. The data needed in the evaluation and strengthening of the pier include location data, ship data, topographic data, bathymetry, and soil survey data. These data, based on their functions, are divided into two categories: (1) *Technical Data*: Technical data is data that is directly related to the planning of the pier, including the size of the ship to dock, the maximum load of the ship, the type of dock bottom soil, the elevation of the tidal water level, sea currents, wave characteristics, and the results of soil investigation. (2) *Non-Technical Data*: Non-technical data is data that supports the planning of the dock. This data includes the presence or absence of facilities for bulk ship loading and unloading activities, such as warehouses, storage, and so on.

Test Result Data Analysis

Pile Driving Record **(PDR)**

PDR or *Pile Driving Record* is a method of recording data during the piling process.

PDA (*Pile Driving Analysis*)

PDA or *Pile Driving Analysis* is a direct testing method for piles that have been staked.

Steel Thickness Test (*Ultrasonic Thickness Gauge*/UTG)

Steel Thickness Test (*Ultrasonic Thickness Gauge* / UTG) is one of the important methods used in the analysis and evaluation of the condition of existing piers that use steel structures as the main material.

***Seismic Shock Test* (SST)**

Seismic Shock Test (SST) is a method of checking the integrity of the pile (*pile*), where this method is a combination of pile analysis and vibration test in one test implementation.

***Pile Integrity Test* (PIT)**

Pile Integrity Test (PIT) is a procedure for determining the integrity of a vertical or inclined pile by measuring and analyzing the speed and response to the force of the pile exerted by an impact driver (hand hammer or similar) that is usually applied axially and perpendicular to the pile head.

In checking the dock, the criteria used still refer to the initial design criteria. The criteria include the function of the pier and the dimensions of the pier. The function of the dock in question is a container and general cargo dock. The dimensions of the pier consist of two segments, namely Pier segment 1 with a size of 184 x 35 m2 (*deck on pile type*) and Pier segment 2 with a size of 181 x 35 m2 (*deck on pile type*).

The planning of the pier is carried out by taking into account the planned life of the main structure, which is 50 years, while other elements such as *portal frames* and *fenders* are maintained periodically and replaced in the event of significant damage.

In this study, the modeling of the existing pier structure was carried out using the SAP2000 structure analysis program version 14.2.0. This model accurately represents the existing conditions of the dock, including geometry, material properties, and loading conditions. Various loading scenarios such as dead loads, live loads (including operational loads from QCC), wind loads, wave loads, and earthquake loads are considered in the analysis.

Berthing Load

The ship's berth load is the force transferred to the dock structure through the *fender* as the ship docks, depending on the weight of the ship, speed, environmental conditions, and *fender characteristics*. In dock design, berthing energy calculations are critical to ensure the structure is able to safely withstand the weight of the ship's berth and provide adequate service, in this case for a 40,000 DWT vessel. This calculation takes into account the dimensions of the vessel, the local environment, and design criteria, the result of which determines the fender specifications, structural strength, and mooring system.

Table 1. Summary of the Results of the Calculation of *Berthing Load*

DATA		***TONNAGE***	***UNIT***
Dead weight ton	DWT	40000.00	tone
Displacement of ship	MD	54000	tone
Length offer all	LOUDSPEAKER	237	m
Draft	D	11.7	m
Beam	B	32.2	m
Hydrodynamic mass coefficient	Cm	1.727	
Berthing velocity	V	0.149	m/sec
Velocity of the ship taken normal to the berth	UN	0.148	m/sec
Gravity	g	9.81	m/sec2
Softness coefficient	CS	1	
Configuration coefficient	CC	1	
Berthing angle	A	6	you

DATA		*TONNAGE*	*UNIT*
Distance of of point of contact from the centre	R	61.398	m
Block coeficient	Cb	0.605	m
Radius of gyration of the ship	K	53.304	
Eccentricity coefficient	m	55.682	m
	THAT	0.430	
		0.500	
Energy at normal condition	In	52.178	t.m
Energy at abnormal condition	Ean	86.09	t.m

RESULT AND DISCUSSION

Dredging Layout

According to the regulations, the seabed depth requirement in the dock pool must range from 1.1 to 1.2 times *the* draft of the largest ship to be docked, which in this case is in the range of 12.8 m to 14 m. This depth is necessary to ensure that the ship can sail and lean safely. To facilitate loading and unloading activities, the procurement of Panamax-sized cranes was chosen because it was in accordance with the size of the largest ship to be served and the depth of the dock pool. The following is a picture that shows *the layout* or plan of dredging that will be carried out in the dock pool area to reach the required seabed depth, as well as ensure that the ship can maneuver freely.

Figure 2. Dredging Layout on Existing Piers

Actual Steel Pile Length (Depth)

In order to ensure the actual depth of the steel *pipe pile* that has been installed, both embedded and unembedded in the ground, as well as to find out its condition after and before the dredging process, an evaluation is carried out based on the data of the Pile *Driving Record* (PDR) results that have been made at the time of the previous pile installation. The PDR data used is for the 1-13-A-G and 30-61-A-G pole rows. However, for pile points that do not have PDR data, namely pile row 14-29-A-G, a pile integrity test (*Pile Integrity* Test / PIT) or *Seismic*

Shock Test (SST) is carried out. This method uses vibration waves generated from impact to detect the presence and condition of piles in the ground, as well as accurately determine the embedded length of the piles. With the combination of PDR data and PIT/SST test results, accurate information can be obtained regarding the actual depth of the steel piles that have been installed.

Table 2. Resume of Pole Depth Results PDR and PIT/SST On Line 1-31-A

As	Pole Length According to PDR Data (m)	Pole Length Per PIT/SST Testing (m)	Existing Embedded Pile Depth (m)	Embedded Pile Depth After Dredging (m)
1	22,0	-	11,0	6,0
2	23,8	-	12,0	7,0
3	22,8	-	11,0	6,0
4	22,0	-	10,2	5,0
5	24,2	-	12,4	7,0
6	22,3	-	10,5	5,0
7	24,8	-	13,0	8,0
8	25,3	-	13,5	8,0
9	24,3	-	12,5	7,0
10	23,8	-	12,0	7,0
11	22,8	-	11,0	6,0
12	22,5	-	10,7	5,0
13	20,6	-	8,8	3,0
14	-	20,6	9,0	1,0
15	-	20,3	8,8	1,0
16	-	16,7	9,0	1,0
17	-	19,2	8,8	1,0
18	-	20,6	7,0	1,0
19	-	20,0	7,0	1,0
20	-	22,0	7,0	1,0
21	-	20,2	7,0	1,0
22	-	20,7	7,0	1,0
23	-	18,8	7,0	1,0
24	-	17,7	7,0	1,0

As	Pole Length According to PDR Data (m)	Pole Length Per PIT/SST Testing (m)	Existing Embedded Pile Depth (m)	Embedded Pile Depth After Dredging (m)
25	-	19,3	7,0	1,0
26	-	18,6	7,0	1,0
27	-	18,2	7,0	1,0
28	-	15,9	5,0	1,0
29	-	17,1	5,0	1,0
30	18,8	-	8,0	2,0
31	18,6	-	8,0	1,0

Steel Thickness Test Results (*Ultrasonic Thickness Gauge*/UTG)

Steel thickness testing using *the Ultrasonic Thickness Gauge* (UTG) tool was carried out on steel structural elements in the form of *steel pipe piles* (SPP) with a diameter of 812.8 mm. This test is carried out on the existing dock to obtain data on the actual condition of the steel elements.

The UTG test on SPP pile steel found on the existing pier can be concluded as follows: (1) SPP (φ812.8) New Pier/Segment 1, with an average value = 15.50 mm (1) SPP (φ812.8) New Pier/Segment 2, with an average value = 15.77 mm.

Table 3. Dimensional Tolerance of Pipe Pile Thickness (Steel Pipe) Based on ASTM A 252

ASTM A 252	
Thickness (t)	The minimum wall thickness at any point shall not be more than 12.5% under the nominal wall thickness specified.
Diameter (D)	The outside diameter of steel pipe piles shall not vary more than ±1% from the diameter specified.
Length (L)	Length as specified with a tolerance of ±1.

Pile Driving Analyzer *(PDA)* Test Results

PDA (*Pile Driving Analyzer*) *Test* is an important direct testing method to evaluate the pile bearing capacity of existing dock structures. Through this test, the axial and frictional capacity of the pole blanket can be determined, and the possibility of damage or discontinuity in the pole can be identified. The results of the PDA *Test* provide critical information regarding the strength of the piles in supporting the load of the pier, thus becoming the basis for determining the necessary repair or reinforcement actions to ensure the safety and reliability of the overall existing pier structure.

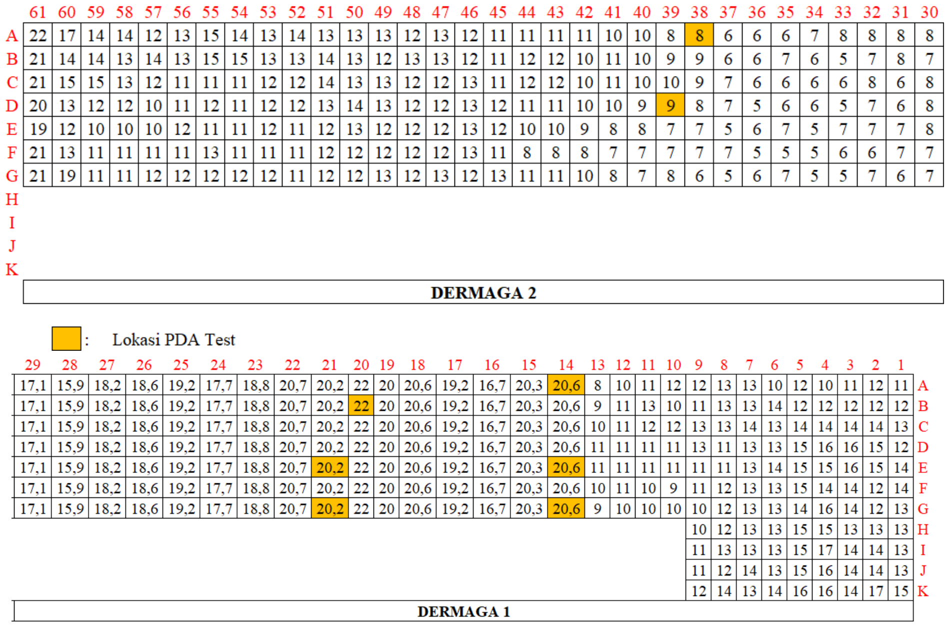


Figure 3. PDA Test Location Plan at Pier 1 and Pier 2

The table below presents the results of PDA testing and CAPWAP (*Case Pile Wave Analysis Program*) analysis that have been carried out at a number of test points at existing pier locations. The data from this test and analysis will be an important basis for conducting a comprehensive evaluation of the current condition of the existing pier structure, including the pile carrying capacity and structural integrity.

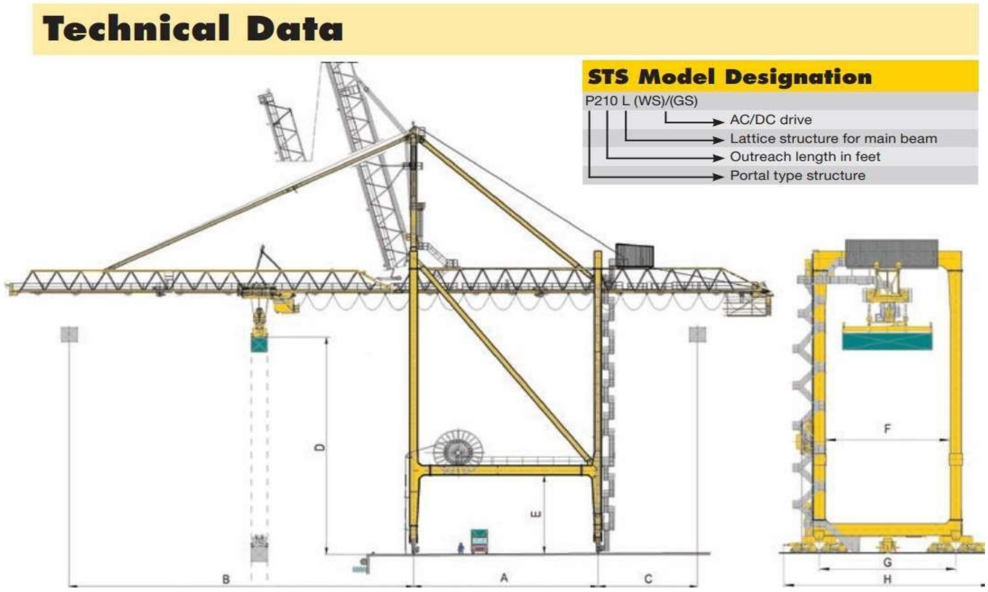
Table 4. Results of PDA Testing and CAP Analysis at Pier 1 and Pier 2

Pile No	Pile Type	Pile Dimension	PDA Bearing Capacity (RMX) (ton)	CAPWAP Total Capacity (ton)	CAPWAP Friction (ton)	CAPWAP Toe (ton)	Total Displacement (mm)	Residual Displacement (mm)
A-14	Steel Pipe	Ø 80 cm	515	492	222	270	28.8	5.0
E-14	Steel Pipe	Ø 80 cm	594	523	209	314	23.4	4.0
G-14	Steel Pipe	Ø 80 cm	481	421	293	128	28.5	1.0
A-38	Steel Pipe	Ø 80 cm	513	503	140	363	14.1	0.3
D-39	Steel Pipe	Ø 80 cm	500	502	87	415	14.0	0.1
B-20	Steel Pipe	Ø 80 cm	505	491	161	330	22.1	5.0
E-21	Steel Pipe	Ø 80 cm	609	605	139	469	19.1	1.5
G-21	Steel Pipe	Ø 80 cm	530	507	114	393	24.8	4.6

Structural modeling for checking the existing structure of Pier 1 and Pier 2 was carried out using the SAP2000 program. In this process, all structural components of the two piers are modeled in detail and accurately based on field data and initial design drawings. Elements such as dock plates, longitudinal and transverse beams, piles, pile *caps*, and other elements are represented in a three-dimensional model using the modeling features available in the SAP2000.

Beban *Container Crane*

The ship unloading/loading facility is using *a container crane*. An illustration of the crane load on the dock is presented in the figure below:



Typical Quayside Crane*	
A: Gantry span	15 - 35 m
C: Backreach	0 - 25 m
E: Clearance under sill beam	12 - 18 m
G: Travel wheel gauge	18.2 m
H: Buffer to buffer	27 m
Wheel spacing	1 - 2 m
Wheels per corner**	6/12 - Seaside
Wheels per corner**	6/12 - Landside
Max. width trolley & main beam/boom	7.6 m

**Dependant on required wheel loads

Typical Feeder - Panamax Crane*	
B: Outreach	30 - 40 m
D: Lift height	24 - 30 m
SWL	40/50 t single | 65 t twin
Hoisting speed	50/125 m/min
Trolley speed	150 - 180 m/min
Travel speed	45 m/min
Wheel load**	30 - 45 t per metre

**Based on 8 wheels per corner at 1 m spacing

Typical Widespan Crane*	
A: Gantry span	35 - 50 m
B: Outreach	30 - 40 m
C: Backreach	15 - 30m
D: Lift height	20 - 25 m
SWL	40/50 t single | 65 t twin
Hoisting speed	50/125 m/min
Trolley speed	180 m/min
Travel speed	100-140 m/min
Wheel load**	40-50 t per metre

**Based on 8 wheels per corner at 1 m spacing

Typical Post Panamax Crane*	
B: Outreach	40 - 45 m
D: Lift height	30 - 35 m
SWL	40/50 t single | 65 t twin
Hoisting speed	60/150 m/min
Trolley speed	180 - 210 m/min
Travel speed	45 m/min
Wheel load**	40 - 55 t per metre

**Based on 8 wheels per corner at 1 m spacing

Typical Design Parameters*	
Classification according to F.E.M.	U7-Q2-A7
In service wind speed	72 km/h (20 m/s)
Out of service wind speed	151.2 km/h (42 m/s)
Ambient temperature range	-40° to 50°C
Frequency	50 Hz to 60 Hz
Voltage	3.3 kV to 20 kV

*Other features, dimensions and design parameters also available

Typical Super Post Panamax/Megamax	
B: Outreach	46 - 73+ m
D: Lift height	30 - 54+ m
SWL	70 t twin | 120 t tandem
Hoisting speed	90/180 m/min
Trolley speed	210 - 240 m/min
Travel speed	45 m/min
Wheel load**	60 - 80 t per metre

**Based on 8 wheels per corner at 1 m spacing

Figure 4. Crane Load Specifications on Pier 1 and Pier 2 Structures

Analysis of Reinforcement at Existing Pier 1 and Pier 2 (With Addition of New Steel Piles)

In an effort to strengthen the existing pier structure, an analysis was carried out to evaluate the effectiveness of adding new steel piles. This method was chosen due to its ease of implementation, relatively lower cost, and significant increase in structural strength.

Based on the results of the analysis, every existing steel pile that has a *stress ratio* value close to or exceeds the critical number of 1.00 needs to be strengthened by adding at least two new steel piles. The new steel piles must be positioned on the right and left sides, or on the front and rear sides of the existing steel piles to be reinforced.

Checking the Strength of Existing *Crane* Beams After Reinforcement/ Addition of Columns

The checking and evaluation of the strength of the existing crane beam is carried out using structural modeling after the reinforcement/addition of steel piles.

Dock Structure Deflection Check

To check and evaluate the deflection of the pier structure, structural modeling is used after the reinforcement or addition of steel piles. The main purpose of checking the deflection of the mast in the case of reinforcement of an existing pier is to ensure that the deformation or lateral shift of the mast due to the working load, such as the horizontal load from waves, currents, ship mooring, or other operational activities, remains within the predetermined tolerance limits. This is important to ensure the stability of the pier structure, prevent damage to other pier elements, such as *the deck* or superstructure, and ensure that the pier can function optimally and safely.

Based on the analysis, it can be concluded that all φ609.6 steel piles installed as additional reinforcement due to *dredging* (BH-02 and BH-03) still meet the set requirements. This is evidenced by the reaction or force that occurs for all cases of loading is under the carrying capacity of the permit, both axial and lateral. Since no reaction or tensile force was found from the *SAP2000 output*, no comparison was made with the bearing capacity of the pole pulling permit. Thus, the number of additions and diameters of the steel piles used proved to be sufficient to bear the load, especially due to the influence of dredging. The results of this analysis indicate that the reinforcement design carried out by adding φ609.6 steel piles has succeeded in increasing the capacity of the structure and ensuring the safety and stability of the construction in withstanding the planned load when facing *dredging conditions*.

Based on the results of checking the carrying capacity of the piles, both axial and lateral, on existing steel piles and new additional piles used for reinforcement, over all the carrying capacity is still below the limit of the permit that has been determined. This shows that the configuration of the addition of steel piles, both at Pier 1 and Pier 2, has met the geotechnical requirements in terms of carrying capacity, so it can be ensured that the designed structure is able to support the planned load safely and in accordance with the applicable technical standards.

Checking *the Settlement* of Existing and Additional Steel Piles After Pier Reinforcement

The analysis of *pile settlement* in the reinforcement of existing piers aims to estimate the decrease due to load, ensure that the decrease does not exceed the tolerance limit that can interfere with operations and damage the structure and evaluate the impact of the decline on the overall integrity of the structure. Summary of the results *of settlement* analysis on steel piles, both existing and additional after reinforcement, in conditions affected by *dredging* and unaffected, all results show settlement values that meet the requirements. The resulting settlement value is below the maximum limit of 15 cm as stipulated in the SNI Geotechnical SNI 8460:2017 standard.

CONCLUSION

Dredging to a depth of 12 meters reduces the current embedded depth of steel piles to 8–8 meters. This reduces the supporting capacity of the pile to withstand the actual load. Current piles may be structurally failing and not meeting safety standards, according to modeling and analysis. As a result, the existing pile must be strengthened by reinforcing its head and adding new steel piles around it. Although the railway beams (*LB1* and *LB2*) have the capacity to withstand the operational load of the railway (*QCC*), evaluation of other structural elements is required. The advice given is to re-verify the soil data after dredging, conduct additional analysis if necessary, and ensure safe operational procedures when operating the railway. Existing beam and plate details must also be evaluated to meet the requirements of the standard.

REFERENCES

Anisadila, C. R., Widhiarto, H., & Fatmawati, L. E. (2023). Replanning of pier structure reinforcement using pile foundations with diameter variations. *Journal of Rab Construction Research, 8*(1), 108–115. http://jurnal.univrab.ac.id/index.php/racic

ASTM International. (n.d.). *ASTM D5882: Standard Test Method for the Determination of the Shear Strength of Soil Using the Direct Shear Test.*

ASTM International. (2018). *ASTM A252-10 (2018): Standard Specification for Welded and Seamless Steel Pipe Piles.* https://doi.org/10.1520/A0252-10R18

Bandari, A., & Sadhukhan, S. (2021). Determinants of per capita water supply in Indian cities with low surface water availability. *Cleaner Environmental Systems, 3.* https://doi.org/10.1016/j.cesys.2021.100062

Chang, Y. L. (1959). Discussion on lateral piles loaded tests. *Feagin Trans, ASCE, 1937*, 272–278.

Chen, K., Lin, Y., Liu, J., He, Z., & Jia, L. (2024). Combined effects of massive reclamation and dredging on the variations in hydrodynamic and sediment transport in Lingdingyang Estuary, China. *Frontiers of Earth Science, 18*(1). https://doi.org/10.1007/s11707-022-1050-x

Czuba, J. A., David, S. R., Edmonds, D. A., & Ward, A. S. (2019). Dynamics of surface-water connectivity in a low-gradient meandering river floodplain. *Water Resources Research, 55*(3). https://doi.org/10.1029/2018WR023527

Forte, R., & Botelho, A. (2021). Debt–performance relationship and firms' international trade activities. *Managerial Finance, 47*(4). https://doi.org/10.1108/MF-04-2020-0162

Masagala, A. A., Bhaskara, A., & Setiawan, D. (2021). Study on the evaluation of the strength of the existing pier structure of Tanjung Priok Port (Case Study: PT. Walie Jaya). *Yogyakarta University of Technology.*

Mundaca, G., Strand, J., & Young, I. R. (2021). Carbon pricing of international transport fuels: Impacts on carbon emissions and trade activity. *Journal of Environmental Economics and Management, 110.* https://doi.org/10.1016/j.jeem.2021.102517

Nilasari, N. V. A., & Kamaludin. (2016). Evaluation of the upper structure of the 1,000 DWT pier against various earthquake zones based on the guidelines for port planning procedures in 2015. *Reka Racana-Online Journal of the National Institute of Technology, 2*(3), 158–169.

Nurrachman, A. D., & Marjanah, I. D. (2023). Korelasi dampak aktivitas perdagangan internasional terhadap kerusakan lingkungan. *PLEDOI (Jurnal Hukum Dan Keadilan), 2*(2). https://doi.org/10.56721/pledoi.v2i2.187

Pittiglio, R. (2023). Counterfeiting and firm survival. Do international trade activities matter? *International Business Review, 32*(5). https://doi.org/10.1016/j.ibusrev.2023.102145

Putri, D. F., & Yuliani, Y. (2023). Implikasi etika bisnis dalam perdagangan internasional: Tinjauan terhadap kegiatan ekspor dan impor. *Jurnal Ilmiah Manajemen, Bisnis Dan Kewirausahaan, 3*(2). https://doi.org/10.55606/jurimbik.v3i2.457

Sandirasegaran, K., & Manap, N. (2016). Impacts of dredging and reclamation projects. *Jurnal Teknologi, 78*(7–3). https://doi.org/10.11113/jt.v78.9506

Sitorus, R., Widyastuti, D. I., & Fuddoly. (2023). Planning for repair and reinforcement of the north side of the construction pier for a 6,000 DWT general cargo ship at the PT Pupuk Kaltim Tersus, Bontang. *ITS Engineering Journal, 12*(1), E46–E53.

Ventura, D., Grosso, L., Pensa, D., Casoli, E., Mancini, G., Valente, T., Scardi, M., & Rakaj, A. (2023). Coastal benthic habitat mapping and monitoring by integrating aerial and water surface low-cost drones. *Frontiers in Marine Science, 9.* https://doi.org/10.3389/fmars.2022.1096594