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STRUCTURAL ANALYSIS AND REINFORCEMENT DESIGN OF DECK-ON-PILE PIER AFTER 12-METER DREDGING

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ABSTRACT

This study addresses the structural integrity and reinforcement needs of a deck-on-pile pier in Sumatra, Indonesia, following a 12-meter dredging operation and the planned use of a Rail Mounted Quay Crane (QCC). The research problem centers on evaluating the pier's existing steel pile foundation strength post-dredging, which reduces embedded pile depth and compromises load bearing capacity and assessing its ability to withstand QCC operational loads. The objectives include analyzing the pier's structural performance, proposing reinforcement designs, and ensuring compliance with safety standards. The methodology combines field data collection (Pile Driving Records, Ultrasonic Thickness Gauge tests, and Pile Integrity Tests) with structural modeling using SAP2000 to simulate load scenarios, including dead loads, QCC operational loads, and environmental forces. Findings reveal that dredging reduces pile embedded depth by 6–8 meters, leading to insufficient load-bearing capacity. Reinforcement strategies, such as adding new steel piles (φ609.6 mm) adjacent to existing ones, are proposed to restore stability. The analysis confirms that the reinforced structure meets geotechnical and deflection standards, with settlements below the 15 cm limit (SNI 8460:2017). The study's implications highlight the importance of pre- and post-dredging structural evaluations for aging piers, offering a practical framework for similar projects. Recommendations include verifying soil data post-dredging and conducting periodic inspections to ensure long-term safety. This research contributes to port infrastructure resilience by integrating empirical testing with advanced modeling to address real-world engineering challenges.

KEYWORDS *Dredging, Structural Reinforcement, Safety Evaluation*

INTRODUCTION

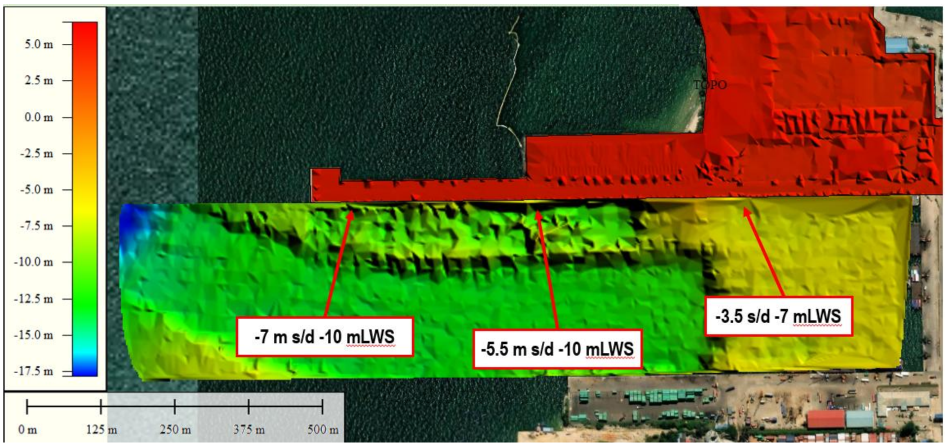
The port is a place of international trade activities and is a center of economic activity (British Standards Institution, 2014; Fanica & Susilo, 2019; Farrosi et al., 2019). In line with the efforts of the central and regional governments for economic development, the port continues to improve itself and continuously equips itself with various facilities and infrastructure that can support the acceleration and smooth operation of ship and cargo service activities (Raga, 2015).

One of the requirements for port development is to have a calm port pool and a relatively deeper water depth (Hafudiansyah & Raya Prima, 2020; Harahap et al., 2024). Because the location of the port plan is in the 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 work of changing the shape of the waterbed to reach the desired depth and width and/or to take the waterbed material that is used for certain purposes (PP No. 5 of 2010) (Herdiansah et al., 2018; Ibrahim & Maal, 2024).

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 (Ines Benge et al., 2024; Japanese Standards Association, 2020).

Due to the development of the use of containers, the size of the ships used is getting larger (Kurniadi & Sudarso, 2024; Kusumaningtyas, 2019; Layang, 2021). To increase the productivity of loading and unloading containers and utilize existing construction, deepening or dredging the berth pond is needed (Layang, 2021; Lutfie, 2017). Based on the regulations, the seabed depth requirement is 1.1 to 1.2 ship drafts, so that 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 there are shallow areas. The type of material dredged is silt soil and very dense sand with a tax return value of 20 to >60 (Nurahman, 2019; Nusantoro, 2017; Pasaribu et al., 2024).

This dredging can cause steel piles to no longer tread on the original soil (seabed), potentially reducing the stability of the structure (Government Regulation of the Republic of Indonesia, 2010; Prasetyo, 2017). 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 (Saputra, 2020; Sari & Chayati, 2023). 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 (Masagala et al., 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 load of the operational load, it is also to determine the maximum pool depth that 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 (da Costa et al., 2020; Satria et al., 2013).



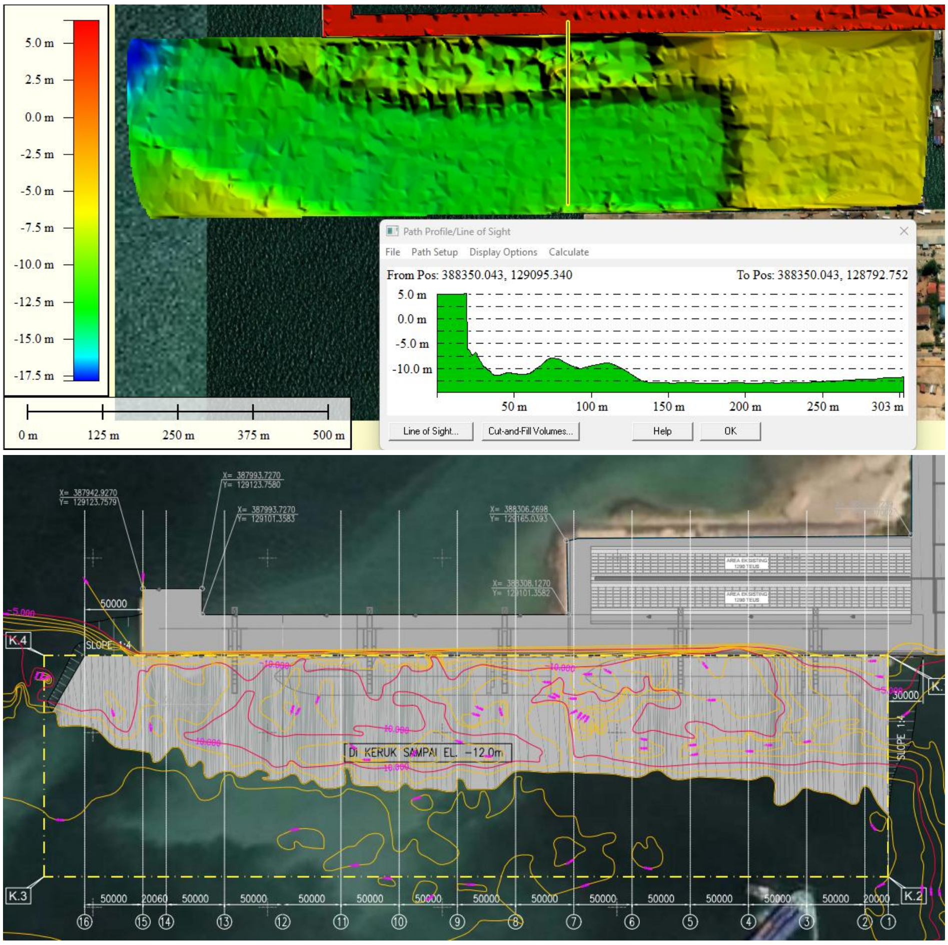


Figure 1. Dredging Layout on XYZ Pier
Source: Secondary Data (2024)

The port serves as a hub for international trade and economic activity. In alignment with central and regional government efforts toward economic development, the port continues to enhance its facilities and infrastructure to support efficient ship and cargo operations (Raga, 2015). A key requirement for port development is maintaining a calm port pool with sufficient water depth. Since the proposed port location lies near coastal waters, dredging is necessary to deepen the harbor pond, enabling vessels to load and unload safely. Dredging involves reshaping the seabed to achieve desired dimensions or extracting materials for specific uses (PP No. 5 of 2010). The process will continue until reaching a layer of hard soil or bedrock.

A pier, defined as a port structure for mooring ships and handling cargo and passengers (Nilasari & Kamaludin, 2016), is central to this study. XYZ Pier in Sumatra, an aging but active facility for containers and general cargo, comprises two segments: Segment 1 (184 × 35 m²) and Segment 2 (181 × 35 m²). Designed as a deck on pile (staked pier), its floor elevation sits at +4.50 m above Low Water Surface (LWS), with a planned water depth of -12.00 m LWS. The structure has a 50-year service life.

Growing container use has necessitated larger vessels, prompting plans to dredge the berth pond for improved productivity. Regulatory standards require a seabed depth of 1.1–1.2 times vessel draft (12.8–14 m). Surveys reveal shallow zones near the pier edges, with dredging targeting silt soil and dense sand (tax return values: 20 to >60). However, dredging risks destabilizing steel piles by displacing their foundational seabed, compromising structural integrity. Unsupported piles may fail to transfer loads, increasing collapse risks. Masagala, Bhaskara, and Setiawan (2021) emphasize evaluating existing piers to assess reliability under operational loads, determine safe dredging depths, and identify reinforcement needs for excess depths.

Plans to operate a Rail Mounted Quay Crane (QCC)—a rail-based dock crane—on the deck on pile segment necessitate reevaluating the pier's capacity. This study addresses three questions: (1) the existing pile foundation's strength post-dredging and under QCC loads; (2) reinforcement recommendations for -12 m dredging; and (3) a deck on pile reinforcement design for QCC loads. The objectives are to analyze the structure's post-dredging and QCC load capacity, propose pile foundation reinforcements, and design QCC-compatible upgrades.

The study's scope includes a 50-year service life assessment of Piers 1 and 2 (see figures), analyzing pre- and post-dredging conditions. Structural modeling incorporates Pile Driving Records (PDR), Pile Integrity Tests (PIT), and Seismic Shock Tests (SST). Pile capacity is cross-checked with PDA test data, and soil data from boreholes BH-01 and BH-02 informs calculations.

This research offers practical benefits: (1) ensuring pier safety post-dredging and QCC deployment; (2) providing reinforcement designs for deck on pile structures; (3) mitigating dredging impacts to -12 m; (4) boosting container-handling efficiency; and (5) serving as a reference for future port projects.

Prior research informs this work. Rubin Sitorus et al. (2023) evaluated a 6,000 DWT cargo pier in Bontang using OCDI 2009, BS 6349-4:2014, and Eurocodes, recommending dredging to -7.48 m LWS, new fenders, and structural patches. Clarissa Rahma Anisadila et al. (2023) redesigned Surabaya's Berlian Pier with varying pile diameters (0.9–1.1 m), identifying 1.0 m × 32 m piles as optimal (capacity: 8,164 tons; total settlement: 48.05 mm). These studies underscore the importance of tailored solutions for pier reinforcement.

RESEARCH METHOD

This research focuses on evaluating the structural integrity of an existing pier located on Batam Island. The study was initiated due to two key factors: planned dredging activities around the pier area and the proposed implementation of a Quayside Container Crane (QCC) on the deck on pile dock segment. The primary objective is to assess whether the pier structure can maintain safe operations following these significant changes, which include both seabed modifications and increased operational loads from the QCC.

Preparatory activities for this research involved three main steps: First, a comprehensive literature review was conducted on pier structure planning and evaluation methodologies to establish a proper framework for assessment. Second, necessary data requirements were identified, including structural specifications, soil characteristics, environmental conditions, and operational parameters. Third, relevant data collection was performed, gathering preliminary design drawings, structural inspection reports, geotechnical investigation results, meteorological and oceanographic data (wind/wave patterns), and operational load specifications.

The evaluation and reinforcement process utilizes secondary data obtained from relevant project authorities. Essential data for this analysis includes: (1) Technical Data - comprising vessel specifications (size and maximum load capacity), seabed soil characteristics, tidal elevation measurements, ocean current patterns, wave dynamics, and geotechnical investigation results; and (2) Non-Technical Data - supporting infrastructure information such as availability of storage facilities, warehouses, and other cargo handling amenities crucial for bulk loading/unloading operations.

Test Result Data Analysis

a. **Pile Driving Record (PDR)**
   PDR or Pile Driving Record is a method of recording data during the piling process.
b. **PDA (Pile Driving Analysis)**
   PDA or Pile Driving Analysis is a direct testing method for piles that have been staked.
c. **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.
d. **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.
e. **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 considering 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 can safely withstand the weight of the ship's berth and provide adequate service, in this case for a 40,000 DWT vessel. This calculation considers 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 offers 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
Distance of point of contact from the centre	R	61.398	m
Block coefficient	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 in normal condition	In	52.178	t.m
Energy at abnormal condition	Ean	86.09	t.m

Source: Processed Data

RESULT AND DISCUSSION

Dredging Layout

According to the regulations, the seabed depth requirement in the dock pool must range from 1 to 2 times with 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
Source: Secondary Data (2024)

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

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)
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
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

Source: Processed Data

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.

Source: Processed Data

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.

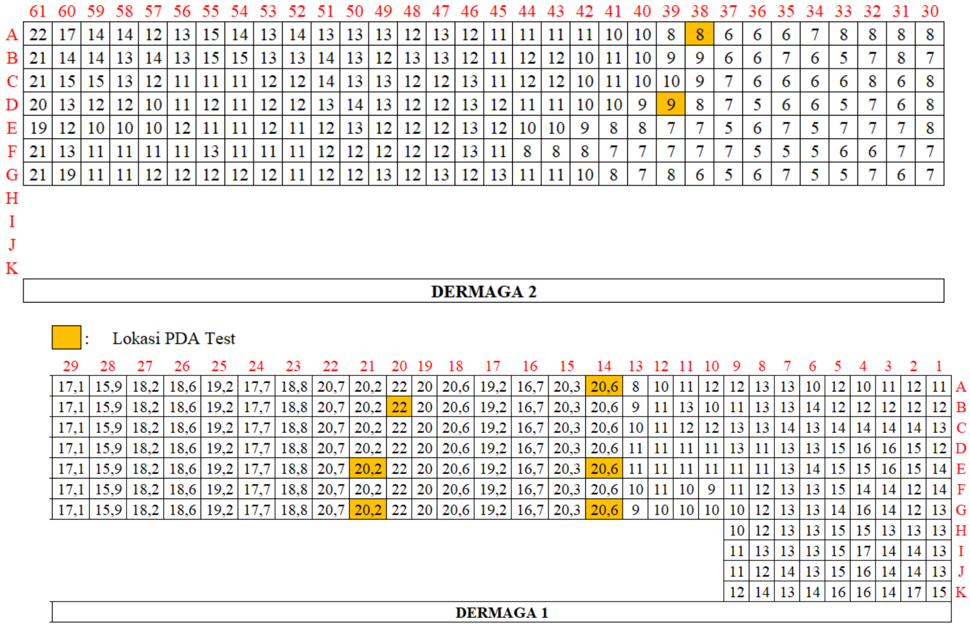


Figure 3. PDA Test Location Plan at Pier 1 and Pier 2

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	CAPWAP				
			Bearing Capacity (RMX)	Bearing Capacity (ton)			Displacement (mm)	
				Total	Friction	Toe	Total	Residual
			(ton)	(ton)	(ton)	(ton)	(mm)	(mm)
A-14	Steel Pipe	**Ø 80 cm**	515	492	222	270	28.8	5
E-14			594	523	209	314	23.4	4
G-14			481	421	293	128	28.5	1

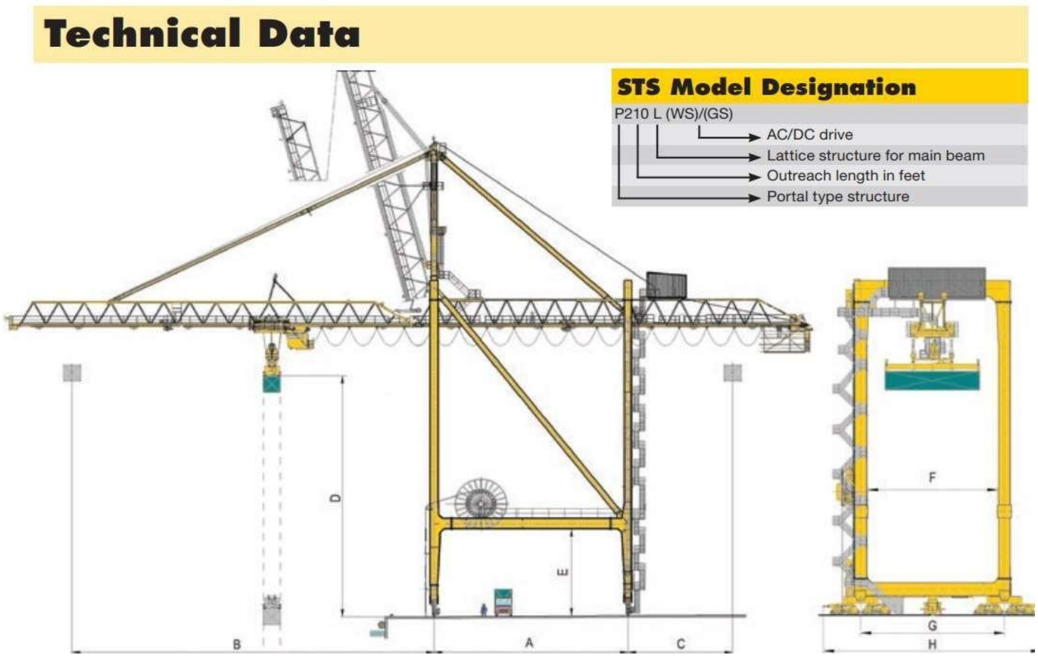
Pile No	PDA	CAPWAP				
	Bearing Capacity (RMX)	Bearing Capacity (ton)			Displacement (mm)	
		Total	Friction	Toe	Total	Residual
	(ton)	(ton)	(ton)	(ton)	(mm)	(mm)
A-38	513	503	140	363	14.1	0.3
D-39	500	502	87	415	14.0	0.1

Pile No	PDA	CAPWAP				
	Bearing Capacity (RMX)	Bearing Capacity (ton)			Displacement (mm)	
		Total	Friction	Toe	Total	Residual
	(ton)	(ton)	(ton)	(ton)	(mm)	(mm)
B-20	505	491	161	330	22.1	5
B-21	609	605	139	469	19.1	1.5
G-221	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.

Container Crane Load

The ship unloading/loading facility is using a container crane. An illustration of the crane load on the dock is presented in the picture 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 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 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 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 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 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)

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, overall, 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

The planned dredging to -12 meters will reduce steel pile embedment to 8-10 meters, compromising their load-bearing capacity and potentially exceeding safe design limits, necessitating reinforcement through pile head strengthening and additional steel piles. While railway beams (LB1/LB2) can withstand Quayside Container Crane (QCC) loads, full structural reassessment is required, including post-dredging soil verification, potential additional analyses, enhanced safety protocols for QCC operations, and evaluation of all beam/plate specifications to ensure compliance with current standards (e.g., BS 6349, Eurocode) for maintaining structural integrity under new operational demands.

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