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STRUCTURAL ASSESSMENT OF EXISTING PILE-SUPPORTED WHARF DUE TO BERTHING FORCE FROM 50.000 DWT SHIPS

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ABSTRACT

This paper describes the structural assessment and strengthening methods of a pile-supported wharf (PSW). The PSW used as the case study in this paper was built in 1998 and designed to have the berthing capacity for accommodating a 40.000 DWT bulk carrier ship. Due to the increasing demand for bulk materials, shipments using a 50.000 DWT bulk carrier ship were carried out. Thus, the berthing force applied to the PSW was more significant than the original design. Furthermore, the depth of the berthing area in front of the PSW must be dredged to accommodate the larger ships' draft. Ferro-scanning (steel reinforcement number and spacing), core drill samples, hammer test, ultrasonic pulse velocity test, and visual inspections were performed as part of the assessment. According to the assessment, the concrete used for the jetty is generally of acceptable quality (high strength, strong compaction, and good aggregate distribution), and cover depths are greater than 40 mm in most spots. A structural analysis to verify the PSW capacity was also completed, and it was found that several beams need to be retrofitted using Carbon Fiber Reinforced Polymer. The analysis also shows that the piles can withstand the new berthing force and the effect of seabed dredging.

Keywords: Pile-Supported Wharf, Assessment, Berthing Force, Retrofit

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1. INTRODUCTION

Pile-supported wharf (PSW) is one of the main port facilities for transferring shiploads and ship berthing. A PSW has a typical design life of fifty years. During its design life, the change of loading scenario could be occurred. Therefore, a structural assessment was needed to analyze the current strength of the PSW against the new loading scenario. The assessment must be thoroughly conducted to check every possible modification that could occur due to the change of loading scenario.

The PSW utilized as a case study in this research was located in Tuban, Indonesia, completed in 1998, and designed to accommodate a 40.000 DWT bulk carrier ship (Figure 1). Shipments were made using a 50.000 DWT bulk carrier ship due to increased demand for bulk supplies. As a result, the berthing force onto the PSW was more than the original design. Additionally, the berthing area in front of the PSW must be dredged to accommodate the larger ships' draft, which caused the pile's free length to increase.

Figure 1. Illustration of the existing PSW

The structural data of the PSW was obtained from the as-build drawing and several non-destructive and destructive tests. Ferro-scanning (steel reinforcement number and spacing), hammer test, core drill samples, ultrasonic pulse velocity test, and visual inspections were performed as part of the assessment. Using the data obtained from the tests and design documents, the structural assessment of PSW was conducted using finite element analysis. Finite element analysis has been widely used for conducting structural assessment of a PSW [1], [2], [3], [4]. Numerical simulation using SAP 2000 was used to analyze the PSW response against the loading scenario. As the PSW observed in this research was situated in Indonesia, which had high seismic risk, it has become essential to analyze the influence of seismic force [5], [6]. The PSW was built 25 years ago; therefore, it is essential to consider the effect of corrosion in a pile in the assessment [7], [8]

Several studies describe different methods for increasing the structural capacity of PSW. Wang et al. [9] research shows that retrofitted PSW using carbon fiber reinforced polymer (CFRP) exhibited reduced deck displacement and remarkable decreases in pile deformation and bending moment. Another material commonly applied for retrofitting the PSW was glass fiber polymer [10]. This research applied the CFRP as the material for retrofitting.

2. METHODS

2.1. Target PSW

The target PSW has a steel pipe pile foundation and a reinforced concrete deck. The configurations for PSW are depicted in Figure 2. The deck elevation is a +4.00 m low water spring (LWS). The deck is supported by steel pipe piles using diameters (Ø) of 811,2 and 1016 mm and sits on a −10 m LWS seabed. Figure 3 describes the transversal configuration of piles. The pile spacing in the transversal direction was 6.25 m. Meanwhile, the pile spacing in the longitudinal direction varies between 6.6 to 8 m. The variation of the piles in the longitudinal direction was caused by the imperfection in the piling process during construction. Figures 2 and 3 were used to develop the finite element models in the following analysis steps.

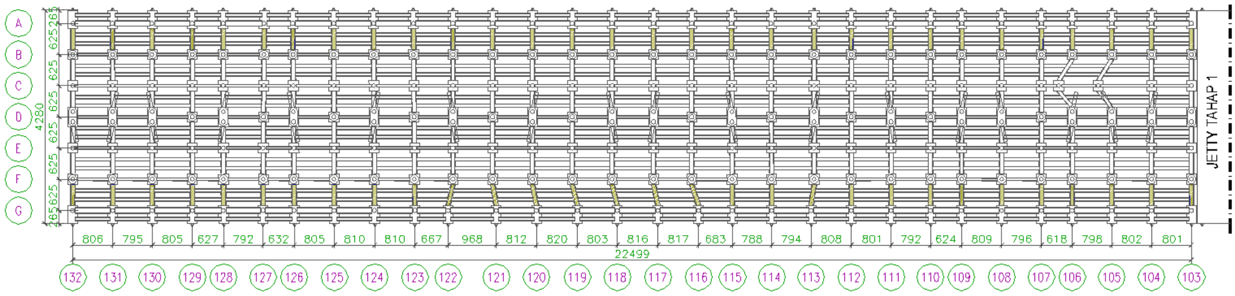

Figure 2. Beams and piles plan of PSW

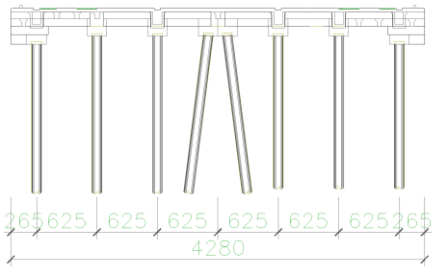

Figure 3. PSW's cross-section

Table 1 shows the soil properties used in this study, obtained from the soil investigation conducted by the port owner. The soil consists of four silty clay layers, where Layer 1 is clayey silt with sand and gravel at the seabed, and Layer 4 is stiff clayey silt soil where the pile's bottom end sits. Based on the as-built drawing documents, the pile's bottom end was at – 31 m from the seabed.

Table 1. Soil properties

Layer	N-SPT	Layer thickness (m)	Soil type
1	1–5	3	Clayey Silt with Sand and Gravel
2	30–36	6	Clayey Silt with Sand and Gravel
3	11–16	20	Sandy Silt with Clay and Sand
4	20–36	20	Clayey Silt

2.2. Destructive and non-destructive test results

The objective of non-destructive testing, particularly the hammer test, is to assess the consistency of concrete by following the guidelines outlined in ASTM C805-02[11]. This test is utilized to assess the consistency of the quality of the current PSW concrete. Twenty points were examined in this verification survey. Testing is conducted on the surface area of the PSW plate and plank fenders at a -90-degree angle. The rebound reading value is between the range of 42.20 to 45.60. The mean reading value of the rebound is 43.36. Therefore, the concrete has an estimated minimum strength of 491.01 kg/cm^2, a maximum strength of 552.44 kg/cm^2, and an average strength of 511.79 kg/cm^2. That shows the concrete has good uniform strength. For the analyses, concrete strength for core drill results was used. Compression test of concrete cylinder obtained from concrete drill shows the average value of fc' = 27.5 MPa for both beams and slabs.

The purpose of conducting a concrete density test using an ultrasonic pulse velocity test, as per ASTM C 597-02[12], is to assess the consistency and density of concrete by measuring the velocity of ultrasonic waves at a frequency of 50 KHz. This test is conducted at a maximum of 10 test points.

The ultrasonic pulse velocity data analysis reveals wave propagation speeds vary between 3390 m/s and 4082 m/s. The average speed figure is 3743 m/s. Based on this data, it is determined that the concrete density falls within a favorable range.

The measurement of the concrete cover thickness and the positioning of the reinforcement is conducted on the slab and fender plank. The rebar locator Proceq Provometer is the utilized instrument. This equipment enables precise measurement of the thickness of the concrete cover, allowing for the evaluation of the effective height of the reinforced concrete structure. The effective height is a fundamental parameter for measuring the cross-sectional capacity of the reinforced concrete structure. Based on the test findings, it can be concluded that the reinforcement of the plate, beam, and plank fender is consistent with the specifications for the concrete cover thickness, the number of reinforcements, and their installation spacing, which is stated in the as-built drawing.

Additionally, visual inspections are conducted to assess the current state of the fenders. It is crucial to accomplish this considering the significance of the Fender's role. The observations above yielded the following results: fourteen fenders were in good condition, twenty-four fenders exhibited mild damage, eleven fenders displayed moderate damage, ten fenders showed severe damage, and one fender was reported as lost. This data will be utilized to assess the fender's capacity to accommodate vessels weighing 50.000 DWT.

2.3. Finite element modelling

SAP 2000 software created a 2D FA model [13] [14]. Piles and beams were modeled as frame elements and rigidly connected. The soil springs with elastic-plastic P-Y curves were used to describe the relationship of soil reaction (P) versus lateral displacement (Y) around the pile. The ship's specification used in this analysis is a 50.000 DWT bulk carrier with 190 m overall length and 12 m draft. Therefore, the seabed must be dredged to – 13.5 m below the low water spring to accommodate the ship draft. In the model, a high-strength steel reinforcement with a minimum tensile strength of 400 MPa was utilized for the reinforced concrete. The steel piles with a diameter of 811.2 mm and a thickness of 16 mm, as well as a diameter of 1016 mm and a thickness of 16 mm, are made from foundation material that meets the quality standards of ASTM A252 Grade 2 "Weldable Structural Steels." These piles have a tensile strength of 415 MPa and a yield strength of 240 MPa. Figure 4 shows the 3D models of the PSW developed using SAP 2000.

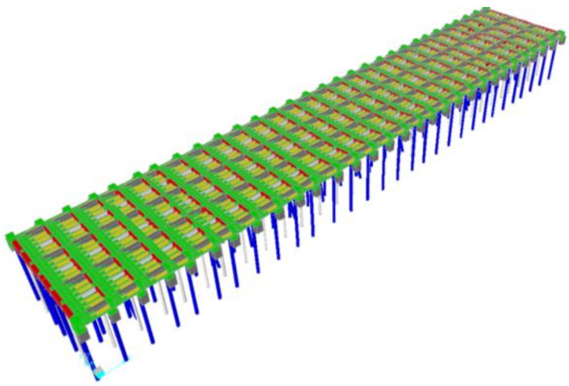

Figure 4. PSW’s 3D Model

The structure is subjected to various loads, including dead load, live load, earthquake load, berthing load, bolder pull load, current load, wind load, and wave load, which are imposed by the standard load at the port. The dead load was automatically computed utilizing the SAP 2000 software. It is derived from the dimensions of the structural elements in the models.

The live loads comprise a uniformly distributed load of 2.5 t/m^2, an 80-ton bulk truck, and a mobile crane with an outrigger load of 70 tons. The PSW pile experienced a wave load of 2.5 kN/m and a current load of 0.9 kN/m. The seismic load was determined using the Indonesian seismic code SNI -1726-2019 [15].

The calculation of the fender load was performed using the formula for kinetic energy. The berthing velocity of the bulk carrier ship, which has a deadweight tonnage (DWT) of 50,000, is 0.2 m/s. Therefore, the kinetic energy that needs to be absorbed by the fender is 26 tons.m. The current fender being utilized is the Rubber Fender Type V 800, which generates a reaction force of 162 tons on the PSW. The applied pulling force of the boulder in this model is 100 tons.

3. RESULT AND DISCUSSION

3.1. Upper Structure

The maximum forces in the structural element can be determined based on the structural analysis findings, including input loading and modeling (Table 2). According to Table 2, the transverse beam has the highest bending moment, measuring 5896 kN.m, whereas the longitudinal beam 2 has the lowest bending moment. This is caused by a rise in the substantial lateral force due to increased ship size. The transverse beam is a structural element that supports the plank fender where the ship makes contact. Therefore, it experienced the highest increase in bending moment value.

Table 2. Bending moment and shear force occurred at beams.

No	Beams	Dimension b/h (cm)	Ultimate Bending Moment (kN.m)		Ultimate Shear Force (kN)	
			Support	Field	Support	Field
1	Crane Beams	130/ 185	2713	2713	1219	828
2	Transverse Beam 1	120/185	5896	3232	4856	2892
3	Longitudinal Beam1	45/110	1183	642	866	420
4	Longitudinal Beam2	45/100	774	825	754	240

Note: *b* is beam width, and *h* is beam height

The previous non-destructive test showed that the beam's required reinforcements remain consistent with the as-build drawing data. The number and diameter of reinforcement rebar are presented in Table 3. Subsequently, the beam capacity is determined based on the provided data in Table 3. The result of the bending moment and shear capacity of the beam are presented in Table 4. The data in Table 4 was contrasted with the internal force experienced by the beam under a new loading scenario (Table 2). The findings of the comparison are presented in Table 5.

Table 3. Reinforcement at PSW's beam

No	Beams	Dimention b/h (cm)	Cover (mm)	Flexural Rebar Diameter (mm)	Shear Rebar Diameter (mm)	Flexural RebarNumber				Shear Rebar Number			
						Support		Field		Support		Field	
						Top	Bottom	Bottom	Top	Number	Space (mm)	Number	Space (mm)
1	Crane Beams	130/ 185	50	32	16	20	32	32	20	6	100	6	150
2	Transverse Beam 1	120/185	50	32	16	8	10	8	10	4	100	4	100
3	Longitudinal Beam1	45/110	50	32	16	5	6	6	5	2	75	2	75
4	Longitudinal Beam2	45/100	50	32	13	5	6	6	5	2	75	2	75

Table 4. Bending moment and shear capacity

No	Beams	Dimension b/h (cm)	Bending Moment Capacity (kN.m)		Ultimate Shear Capacity (kN)	
			Support	Field	Support	Field
1	Crane Beams	130/ 185	5921	5921	7904	5772
2	Transverse Beam 1	120/185	4985	4985	5656	5656
3	Longitudinal Beam1	45/110	1640	1640	1358	1358
4	Longitudinal Beam2	45/100	1640	1640	1358	1358

Note: *b* is beam width, and *h* is beam height

Table 5 reveals that a transverse beam cannot bear the operating load. This is because the moment resulting from the load applied at the support position exceeds the moment capacity of the structure. Consequently, the beam was retrofitted utilizing Carbon Fiber Reinforced Polymer (CFRP). The CFRP requirements include a tensile strength of 2800 MPa, an elastic modulus of 160,000 MPa, a width of 100 mm, and a thickness of 1.2 mm. The calculation of CFRP requirements is based on the residual moments derived from the reduction of the moment that exceeds the moment capacity. The analytical results indicate the requirement for 4 CFRP strips to be inserted at the top location of the beam.

Table 5. Evaluation of beam strength

No	Beams	Dimension b/h (cm)	Bending Moment Capacity (kN.m)		Ultimate Shear Capacity (kN)	
			Support	Field	Support	Field
1	Crane Beams	130/ 185	Accept	Accept	Accept	Accept
2	Transverse Beam 1	120/185	Fail	Accept	Accept	Accept
3	Longitudinal Beam1	45/110	Accept	Accept	Accept	Accept
4	Longitudinal Beam2	45/100	Accept	Accept	Accept	Accept

Note: *Accept* means the force < the capacity; *Fail* means the force > the capacity.

3.2. Pile Structure

The current pile structure consists of steel piles with a diameter of 811.2mm and a thickness of 16mm, as well as 1016mm piles with a thickness of 16mm. These piles are made of ASTM A252 Grade 2 "Weldable Structural Steels". The material has a tensile strength of 415 MPa and a yield strength of 240 MPa. The maximum allowable deflection of the pile is H/300 or a maximum of 100mm.

Based on the data from Tables 5 and 6, it was determined that the ratio of capacity to force for pile diameters 811.2 and 1016 is less than 1. Therefore, the capacity of the pile still meets the requirements. Furthermore, assessing the soil's bearing capacity is imperative to withstand the load exerted on it. The findings from the analysis of the bearing capacity are presented in Table 7. Based on the comparison, it has been determined that the soil's bearing capacity is satisfactory, and the pile's structure remains safe.

Table 5. Evaluation stell ratio of the pile with diameter 811,2 t=16mm

TABLE: Steel Design 1 - Summary Data - AISC-LRFD93			
Frame	**DesignSect**	**Ratio**	**Combo**
Text	Text	Unitless	Text
1	SPP 812 t=16mm	0.426025	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
2	SPP 812 t=16mm	0.403479	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
88	SPP 812 t=16mm	0.901234	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
89	SPP 812 t=16mm	0.929068	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
90	SPP 812 t=16mm	0.579633	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C

Table 6. Evaluation stell ratio of the pile with diameter 1016 t=16mm

TABLE: Steel Design 1 - Summary Data - AISC-LRFD93			
Frame	**DesignSect**	**Ratio**	**Combo**
Text	Text	Unitless	Text
121	SPP 1016	0.484	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
352	SPP 1016	0.881	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
353	SPP 1016	0.901	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
354	SPP 1016	0.646	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
355	SPP 1016	0.602	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
356	SPP 1016	0.813	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
357	SPP 1016	0.820	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C
358	SPP 1016	0.752	U10=1.2DL+1.6LLU+1.0WL+1.6BL+1.2C

Table 7. Evaluation of Pile Bearing Capacity

Pile diameter (mm)	**Bearing Capacity (t)**	**Pile Reaction (t)**	**Evaluation (Bearing capacity > Pile Reaction)**
812	264	295	Accepted
1016	405	410	Accepted

Deflection control aims to ensure that the greatest deflection in buildings remains below the permissible deflection limit (Table 8). The horizontal deflection allowances of 100 mm can be found in Table 1 of "BS 6349-2: 2010". The research revealed a maximum deflection of 99.8mm, slightly under 100mm.

Table 8. Piles deflection

TABLE: Joint Displacements			
Joint	**OutputCase**	**U1**	**U2**
Text	Text	mm	mm
182	U11=1.11DL+0.1LLU+EQx	99.850	27.119
182	U12=1.11DL+0.1LLU+EQy	48.633	77.273
182	I1=1.0D+1.0LLU+0.6WL+1.0C	19.232	-7.194
182	I2=1.0D+1.0LLT+0.6WL+1.0C	19.327	-7.461
182	I3=1.0D+1.0LLMC+0.6WL+1.0C	19.341	-7.530
182	I5=1.0DL+0.75LLU+0.45WL+1.0FL+1.0C	20.128	-13.753
182	I6=1.0DL+1.0LLU+0.6WL+1.0BL+1.0C	18.246	0.474
182	I4=1.0D+1.0LLMSL+0.6WL+1.0C	19.321	-7.556

4. CONCLUSIONS

To study the PSW's ability to withstand the load of 50.000 DWT ships, we use finite element analysis and non-destructive and destructive tests to assess the PSW condition. The main conclusions drawn from this study are as follows:

1. The non-destructive and destructive tests can provide reliable results about the PSW's current conditions. The result shows that there is a slight degradation of the concrete strength. It also shows that the diameter and number of rebar installed in beams are consistent with the as-built drawing.
2. The analysis shows that the transverse beam cannot bear the operating load. This is because the moment resulting from the load applied at the support position exceeds the moment capacity of the structure. Consequently, the beam was retrofitted utilizing Carbon Fiber Reinforced Polymer (CFRP).
3. The analysis finds that the piles still meet the requirement to withstand the working load. The pile's strength ratio, soil bearing capacity, and pile deflection have shown satisfactory results.

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