Jurnal Teknik Sipil & Perencanaan 25 (2) (2023) p 117 - 127

JURNAL TEKNIK SIPIL & PERENCANAAN

10.15294/jtsp.v25i1.34922

The Study of The Impact of Onshore Harbor Layout on Coastal Sedimentation and Erosion at Pekalongan Beach

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Abstract. Pekalongan City is an area that frequently experiences floods. In response, the government has launched a flood management program for the Pekalongan area, which includes the relocation of the National Fishery Harbor Pekalongan. The construction of the Pekalongan Onshore Harbor will change marine hydrodynamics, current, waves and sediments. To address these issues, it is necessary to conduct a study of these changes. According to the modeling results, the maximum current speed in the harbor pool ranges from 0 to 0.28 m/s, while the maximum wave height in the harbor pool falls within the range of 0 to 0.40 meters. The bed level change at the end of modeling in the harbor pool is 0.108 mm. Notably, the construction of the Pekalongan Onshore Harbor, as per the planned layout, induces hydrodynamic changes. An indicator of a hydrodynamics change is the alteration in currents at T4 and T5 in each model. In the proposed harbor layout, T4 and T5 exhibit a decrease in current speed, while the wave height remains relatively consistent. This change reduces erosion at T5 and even leads to sedimentation at T4 within the planned harbor layout.

Keywords: *Current, Wave, Bed Level Change, Harbor Layout*

INTRODUCTION

Pekalongan City is an area characterized by significant land subsidence, as illustrated in Figure 1. Based on Figure 1, land subsidence is measured at the rate of 10.5 cm/year in agricultural areas and 7.7 cm/year in areas designated for a combination of agricultural and residential purposes. This phenomenon has contributed to the exacerbation of flooding in Pekalongan City.

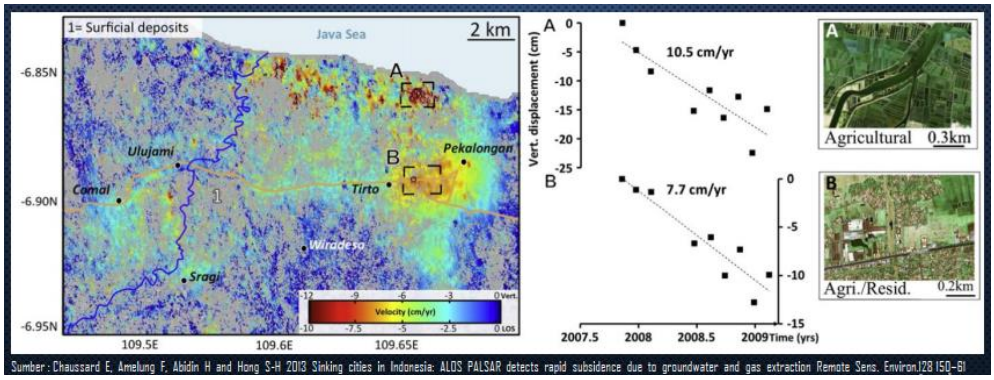


FIGURE 1. Rate of Land Subsidence in Pekalongan City [1]

Therefore, the government has devised a flood management strategy for the Pekalongan area. This strategy involves the creation of a flood control program by building a retention pond and weir near the mouth of the Loji River in Pekalongan. As a consequence of these developments, the Pekalongan National Fisheries Harbor (PPNP) and the ships mooring along the Loji River must be relocated. The government plans to build Pekalongan Onshore Harbor, located east of the mouth of the Loji River. Flood management programs have been carried out several times on the north coast of Java, including Demak. To control the flooding, the government plans to build a sea wall.

The construction of the Pekalongan Onshore Harbor will change marine hydrodynamics, changes in current patterns, waves, and sediment transport. The changes extend beyond the harbor pool and impact the surrounding areas. To address these potential issues and mitigate adverse impacts, a comprehensive study of the layout is essential. This proactive approach to review can help avert losses that may arise from harbor infrastructure development without proper consideration [9]. Therefore, it is necessary to model the construction layout of Pekalongan Onshore Harbor and its effect on coastal sedimentation and erosion.

RESEARCH METHODOLOGY

The research is conducted in the Onshore Harbor area, Pekalongan City, Central Java Province, as shown in Figure 1 and 2. This harbor will be located between the mouths of the Loji River and the Banger River. The Onshore Harbor is designed to replace the previous Nusantara Pekalongan Fisheries Harbor (PPNP), which was previously located in the upstream in the Loji River estuary.

This research is structured into three phases: modelling of existing conditions, modelling of harbor layout, and comparison of the two models. The modelling of the existing condition is carried out with the MIKE DHI application with the coupled model MIKE 21 feature. The modelling was conducted over four seasons: the western monsoon, the first transition season, the eastern monsoon and the second transition season. The purpose of modelling the existing condition is to determine the initial condition at the location of the harbor plan. Notably, at the time of this research, there was a groyne positioned perpendicular to the shoreline within the Pekalongan Onshore Harbor area. It is important to mention that this groyne will be dismantled as part of the Pekalongan Onshore Harbor project. Consequently, the modeling of the existing conditions will not incorporate the presence of this groyne. Figure 2 provides an overview of the location in its existing state.

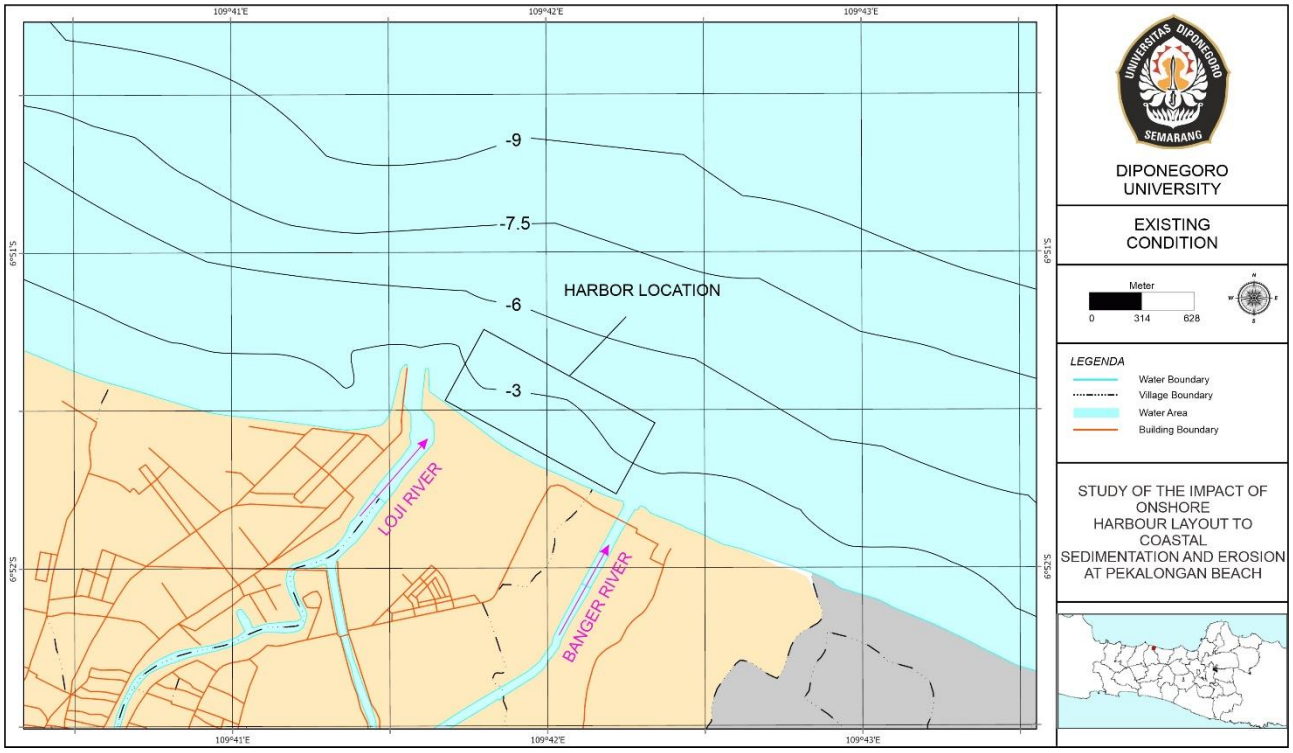


FIGURE 2. Research Location

The harbor layout model is essentially an extension of the existing condition model with the addition of the harbor layout. This layout is provided by the Rijeksdienst Voor Ondornemend (RVO) Nederland and features an open harbor pool mouth on the eastern side of the harbor layout. An overview of the placement of the layout modelling is at the harbor pool and the mouth of the harbor pool (Figure 3). The maximum current velocity and wave height in the harbor pool are regulated in the 1981 Directorate General of Fisheries regulations, with maximum values set at 0.4 m/s and 0.5 m, respectively.

The comparison of the two models consists of a comparison of currents, waves and sedimentation and erosion at selected points of observation. The observation point is taken 5 (five) points. The five points have coordinates (356150, 9241600) for observation point 1, coordinates (356500, 9241400) for observation point 2, coordinates (356500, 9241400) for observation point 3, coordinates (356700, 9241360) for observation point 4 and coordinate (355770, 9242000) for observation point 5.

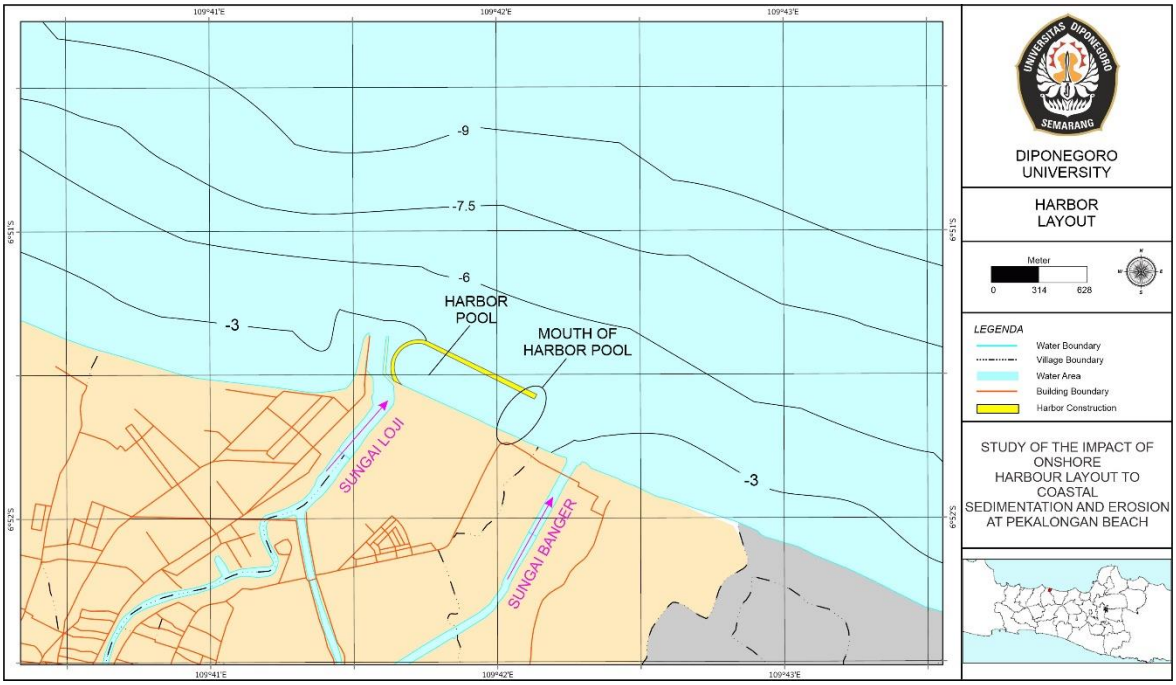
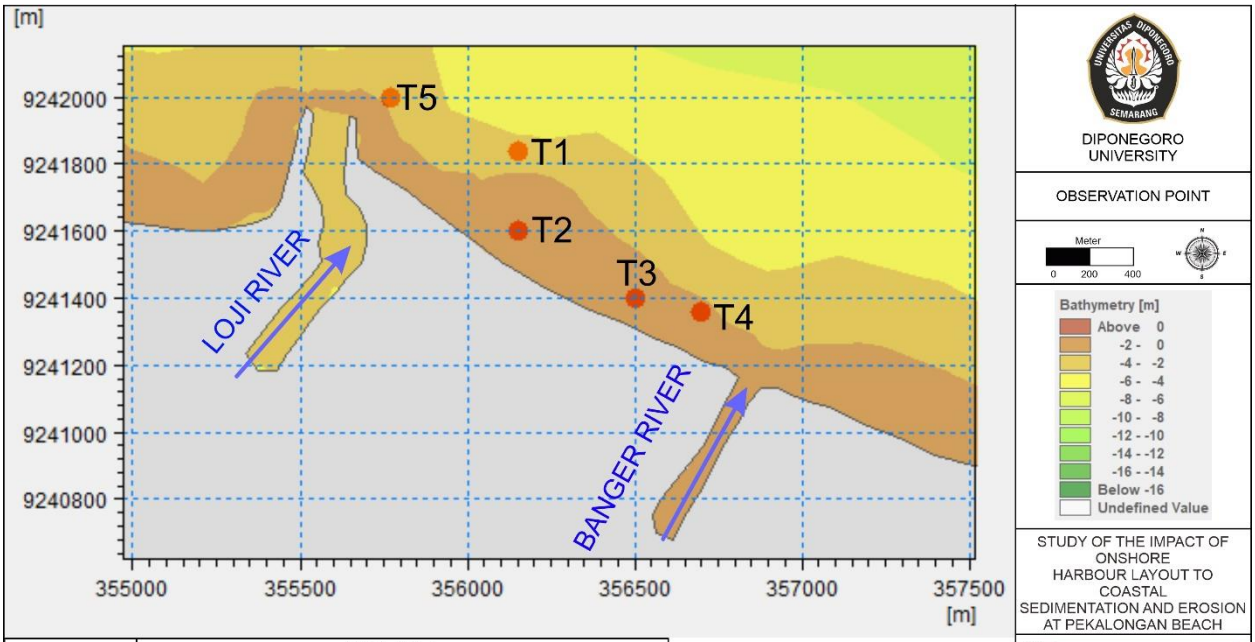


FIGURE 3. Harbor Layout



Koordinat	Titik Tinjau				
	1	2	3	4	5
X	356150	356150	356500	356700	355770
Y	9241840	9241600	9241400	9241360	9242000

FIGURE 4. Observation Point

The Hydrodynamic Module of MIKE21 is a general numerical modeling system designed for modeling water level and flow simulations in estuaries, bays and beaches. This model can simulate two-dimensional unsteady flow in a single layer fluid (vertically homogeneous) or in three-dimensional flow. The MIKE21 Hydrodynamic Module serves as the basic module in the MIKE21 Flow Model Program [2].

The hydrodynamic model, specifically the two-dimensional hydrodynamic model used by MIKE21, is based on the conservation of mass and momentum integrated in the vertical column [2]. By inputting supporting data such as bathymetry data, current data, river data, and the sediment quantities in the area, the model generates results pertaining to

the water level, current velocity, discharge, and sedimentation over a defined time period.
The formula is continuity: [2]

$$\frac{\partial \zeta}{\partial t} + \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

The momentum formula x and y component: [2]

$$\frac{\partial u}{\partial t} + \frac{\partial}{\partial x}\left[\frac{u^2}{h}\right] + \frac{\partial}{\partial y}\left[\frac{uv}{h}\right] + gh\frac{\partial \zeta}{\partial x} + \frac{gu\sqrt{u^2+v^2}}{c^2+h^2} = 0 \quad (2)$$

$$\frac{\partial u}{\partial t} + \frac{\partial}{\partial y}\left[\frac{u^2}{h}\right] + \frac{\partial}{\partial x}\left[\frac{uv}{h}\right] + gh\frac{\partial \zeta}{\partial y} + \frac{gu\sqrt{u^2+v^2}}{c^2+h^2} = 0 \quad (3)$$

Notes:
h (x,y,t) : water depth (m)
∂ (x,y,t) : variables that vary with space and time
ζ (x,y,t) : surface elevation (m)
c (x,y) : chezy resistance ($m^{1/2}/s$)
g : gravitation (m/s^2)

RESULTS AND DISCUSSION

The modeling results for existing conditions include assessment of currents, waves, sedimentation, and erosion with values reaching their maximum for each season. The maximum current speed during the west season, transition season I, east season and transition season II are recorded at 0.08 to 0.56 m/s, 0.15 to 0.70 m/s, 0.06 to 0.54 m/s and 0.15 to 0.65 m/s, respectively. The wave heights in these seasons vary from 0.32 to 0.60 meters, 0.45 to 0.70 meters, 0.32 to 0. 60 meters, and 0.35 to 0.65 meters.

Sediment and erosion modeling are based on changes in bed level. Bed level changes during the west season, transition season I, east season and transition season II range from – 0.16 to – 4.45 mm, – 8.9 to 4.44 mm, – 2.6 to 5.3 mm and – 8.3 to 0.76 mm, respectively. Recapitulation of the existing condition modeling can be seen in Table 1. Based on these modeling results, it can be concluded that the harbor location has high currents, waves, and bed level change, justifying the need for harbor construction..

TABLE 1. Recapitulation of Modeling Result

Modeling Type	Season			
	West	Transition I	East	Transition II
Current Velocity (m/s)	0.08 s/d 0.56	0.15 s/d 0.70	0.06 s/d 0.54	0.15 s/d 0.65
Wave Height (m)	0.32 s/d 0.60	0.45 s/d 0.70	0.32 s/d 0.60	0.35 s/d 0.65
Bed Level Change (mm)	– 0.16 s/d – 4.45	– 8.9 s/d 4.44	2.6 s/d 5.3	– 8.3 s/d 0.76

The results of the harbor layout modeling of currents, waves, sedimentation, and erosion have been obtained at their maximum values in each season, The maximum current velocity in the harbor pool during the west season, transition season I, east season and transition season II ranges from 0 to 0.24 m/s, 0 to 0.12 m/s, and 0 to 0.10 m/s, respectively. The maximum current speeds at the mouth of the harbor pool during these seasons are 0.16 to 0.28 m/s, 0.16 to 0.28 m/s, 0.10 to 0.25 m/s and 0.10 to 0.20 m/s. respectively. The wave heights in the harbor pool during the west season, transition season I, east season and transition season II range from 0 to 0,16 meters, 0 to 0.24 meters, 0 to 0.20 meters and 0 to 0.16 meters, respectively. The wave heights at the mouth of the harbor pool during the west monsoon, transition season I, east monsoon and transition season II are 0.16 to 0.40 meters, 0.24 to 0.40 meters, 0.20 to 0.40 meters and 0.16 to 0.40 meters, respectively.

The bed level changes in the harbor pool during the west season. transition season I, east season, and transition season II range from 0.018 mm, 0.08 mm, 0.108 mm, and 0.057 mm, respectively. The bed level changes at the mouth of the harbor pool during the west season, transition season I, east season, and transition season II are 0.55 mm, 0.79 mm. 0.887 mm, and 1.38 mm, respectively. A recapitulation of the planned harbor layout modeling can be seen in Table 2. Based on the results of the harbor layout modeling, it can be concluded that the harbor layout has effectively reduced current speed and wave height. Bed level changes in the harbor layout occur due to sedimentation, although these changes are comparatively small when compared to the sedimentation observed in the existing conditions.

TABLE 2. Recapitulation Modeling on Harbor Layout

Modeling Type	Location	Season			
		West	Transition I	East	Transition II
Current Velocity (m/s)	Harbor Pool (T2)	0 s/d 0.24	0 s/d 0.12	0 s/d 0.10	0 s/d 0.10
	Mouth of the Harbor Pool (T3)	0.16 s/d 0.28	0.16 s/d 0.28	0.10 s/d 0.25	0.10 s/d 0.20
Wave Height (m)	Harbor Pool (T2)	0 s/d 0.16	0 s/d 0.24	0 s/d 0.20	0 s/d 0.16
	Mouth of the Harbor Pool (T3)	0.16 s/d 0.40	0.24 s/d 0.40	0.20 s/d 0.40	0.16 s/d 0.40
Bed Level Change (mm)	Harbor Pool (T2)	0.018	0.08	0.108	0.057
	Mouth of the Harbor Pool (T3)	0.55	0.79	0.887	1.38

The comparison between the existing condition and the harbor layout is based on the observation point, with five observation points designated for each model. These five observation points represent key locations on the harbor layout. Observation point 1 is situated outside the harbor pool, directly exposed to waves in the harbor layout model. This location requires examination to assess the impact of the harbor layout on areas not shielded by the harbor structure. Observation point 2 is located in the planned harbor pool, while Observation Point 3 is positioned at the mouth of the harbor pool. Observation Point 4 is strategically placed to characterize currents, waves, and sediment transport following changes around the port layout, particularly to the east of the harbor layout. Observation point 5 is situated on the west side of the harbor, describing an area without protection from the harbor layout structure, but where no harbor structure is present on the south side of the observation point. A comparative recapitulation of the existing conditions and the harbor layout based on the observation point can be seen in Table 3.

TABLE 3. Comparison of Modeling Results for Existing Conditions and Harbor Layout Based on Observation Points

Type of Condition	Type of Modeling	Observation Review	Season			
			West	Transition I	East	Transition II
Existing Condition	Current Velocity (m/s)	T1	0.55	0.462	0.454	0.516
		T2	0.645	0.54	0.55	0.551
		T3	0.665	0.542	0.51	0.537
		T4	0.665	0.525	0.37	0.51
		T5	0.715	0.625	0.575	0.68
	Wave Height (m)	T1	0.55	0.578	0.504	0.545
		T2	0.53	0.597	0.55	0.521
		T3	0.558	0.595	0.533	0.589
		T4	0.54	0.55	0.475	0.54
		T5	0.64	0.65	0.61	0.62
	Bed Level Change (mm)	T1	-18.61	-28.41	-18.19	-37.65
		T2	-4.45	-8.91	-2.59	-8.33
		T3	-0.16	4.44	5.3	0.77
		T4	18.2	-40.2	-62.6	-10.3
		T5	-43.5	-65.4	-75.6	-65.4
Harbor Layout	Current Velocity (m/s)	T1	0.582	0.492	0.489	0.569
		T2	0.054	0.073	0.083	0.089
		T3	0.143	0.13	0.08	0.132
		T4	0.284	0.185	0.12	0.125

Type of Condition	Type of Modeling	Observation Review	Season			
			West	Transition I	East	Transition II
		T5	0.508	0.46	0.505	0.46
	Wave Height (m)	T1	0.525	0.602	0.542	0.569
		T2	0.118	0.135	0.144	0.139
		T3	0.4	0.372	0.368	0.336
		T4	0.456	0.463	0.45	0.471
		T5	0.596	0.625	0.56	0.594
	Bed Level Change (mm)	T1	0.629	6.588	6.766	6.906
		T2	0.017	0.08	0.108	0.016
		T3	0.55	0.79	0.89	-0.26
		T4	-0.255	1.058	24.805	0.0695
		T5	-7.01	-51.21	-51.99	-13.52

The comparison of T1 of the existing condition and T1 of the harbor layout will show changes in sediment transport if a longshore breakwater is built. The maximum current speed at T1 in existing conditions and when there is a harbor layout is 0.55 m/s and 0.582 m/s, respectively. The maximum wave heights are 0.578 meters and 0.62 meters, respectively. The bed level changes for the 4 seasons are -100.44 mm and 20.89 mm, respectively. T1 in the existing condition and T1 in the condition with the harbor layout have high currents and waves but different bed level change results. Existing conditions experience erosion, while the harbor layout experiences sedimentation. The difference is related to the location or presence of a breakwater. The distance between T1 and the coastline in the excitation conditions is still quite far, so the waves have not stopped or experienced reflection, so the waves can still move further to approach the shoreline. As a result, the sediment material does not come to a complete stop at T1. The T1 comparison graph of the existing condition and the planned port layout can be seen in Figure 5, section A.

T2 on the harbor layout is the harbor pool. The current velocities at T2 in existing conditions and with a harbor layout are 0.645 m/s and 0.089 m/s, respectively. The maximum wave heights are 0.597 meters and 0.139 meters, respectively. Bed level changes for the 4 seasons are -23.84 mm and 0.22 mm, respectively. The comparison of the two conditions shows that the smaller the currents and waves, the smaller the sediment transport that occurs. The T2 comparison graph of existing conditions and planned port layout can be seen in Figure 5, section B.

T3 on the harbor layout is the mouth of the harbor pool. The maximum current speed at T3 in existing conditions and harbor layout is 0.655 m/s and 0.143 m/s. respectively. The maximum wave heights are 0.595 meters and 0.400 meters. respectively. Bed level changes for the 4 seasons are 9.83 mm and 1.96 mm. respectively. T3 on the harbor layout is the mouth of the harbor pool. Because T3 in the planned port layout is the mouth of the harbor pool, it is necessary to analyze the feasibility based on the 1981 Directorate General of Fisheries regulations. The maximum wave height at T1 is 0.400 meters, while the maximum current speed is 0.143 m/s. This shows that the planned port layout is suitable for use based on the 1981 Directorate General of Fisheries regulations because the maximum current velocity for PPN is 0.4 m/s and the wave height is 0.5 meters, The T3 comparison graph of the existing condition and the planned port layout can be seen in Figure 5. section C.

T4 on the harbor layout is east of the harbor layout. T4 is a location to describe the characteristics of currents. waves. and sediment transport after conditions around the port layout. especially to the east of the harbor layout. The maximum current velocities at T4 at the existing conditions and when there is a harbor layout are 0.655 m/s and 0.284 m/s, respectively. The maximum wave heights are 0.550 and 0.471 meters, respectively. Bed level changes for the 4 seasons are -94.81 mm and 3.35 mm, respectively. T4's harbor layout is adjacent to the mouth of the harbor pool. If the current characteristics are compared with those of the harbor pool (seen from the T3 current characteristics). it can be concluded that the decrease in velocity in the harbor pool has at least started from T4. This shows that the current diversion occurred not right at the mouth of the harbor pool but further before the mouth of the harbor pool. The wave characteristics at that location remain high in the direction of the coastline. This causes sedimentary material from the high seas to be carried away by the waves and settle at the T4 location so that it experiences sedimentation, but when compared to T3, it is found that the T4 sedimentation is greater. This shows that the current that enters the harbor pool carries sediment material that settles in the harbor pool and the mouth of the harbor pool. The T4 comparison graph of the existing condition and the planned port layout can be seen in Figure 5, section D.

T5 in the harbor layout is on the west side of the harbor layout. The maximum current velocities at T5 at existing

conditions and when there is a planned harbor layout are 0.715 m/s and 0.508 m/s, respectively. The maximum wave heights are 0.650 meters and 0.625 meters, respectively. Bed level changes for the 4 seasons are -242.98 mm and -123.73 mm, respectively. The T5 harbor layout has a lower current velocity than the existing condition. This is impacted by the position of the breakwater perpendicular to the coast on the west side of the harbor layout. The breakwater redirects the current from the west, resulting in smaller current velocities in harbor layout T5. This causes scour and sediment transport at T5, but not as much as T5 in the existing conditions, so that erosion at T5 in the harbor layout is not as big as T5 in the existing conditions. The T5 comparison graph of the existing conditions and the planned port layout can be seen in Figure 5, section E.

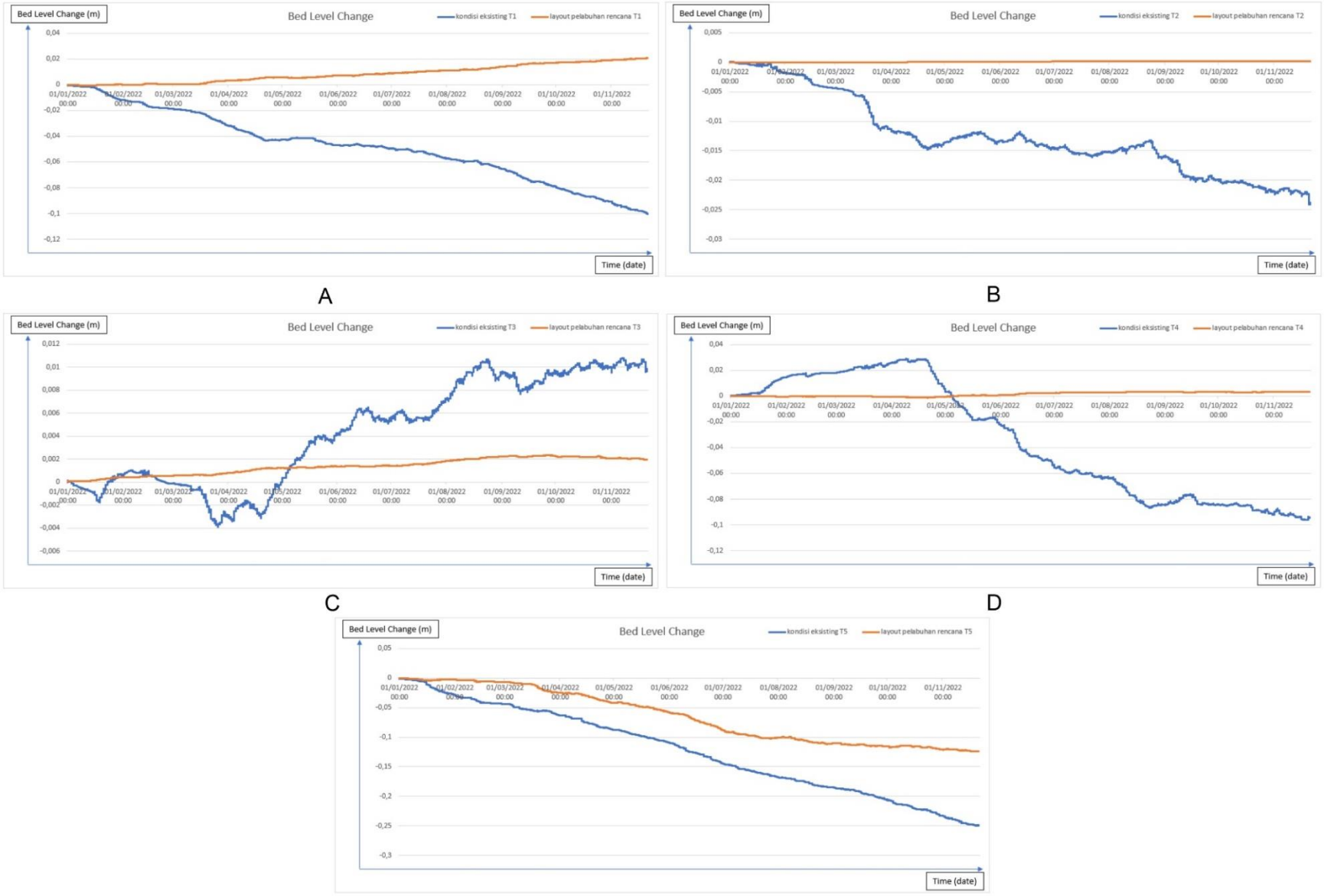


FIGURE 5. The Comparison Graph of Bed Level Change of Existing Condition and Harbor Layout

CONCLUSION

Based on the results and discussion of the research. the following conclusions can be drawn:

1. The modeling of existing conditions indicates that current velocities at the harbor location range from 0.06 to 0.70 m/s, and wave heights vary from 0.32 to 0.70 meters. These currents and waves lead to significant erosion at most harbor locations. Therefore, the construction of a coastal structure with the appropriate shape and proportions is essential to meet the standards set by the Directorate General of Fisheries in 1981 for the establishment of a National Fishery Harbor.
2. The modeling of the harbor layout demonstrates that the planned harbor construction adheres to the proper shape and proportions. This is evident in the reduction of current speeds by up to 0.143 m/s and wave heights by up to 0.400 meters at the harbor pool's mouth. Moreover, the location within the harbor pool experiences lower currents and waves compared to the mouth of the harbor pool. Consequently, the proposed port layout is suitable for Pekalongan Onshore Harbor.
3. The comparison between the existing conditions and the harbor layout reveals that the construction of Pekalongan Onshore Harbor will influence the current and wave characteristics at specific locations. Areas with low currents but high waves will experience substantial sedimentation, such as T4. Locations with strong currents and waves, like T1 and T5, will undergo significant sediment transport, resulting from both erosion and sedimentation. Notably, T1 experiences sedimentation not solely due to high waves but also because of high current velocity. This suggests that material eroded at T5 is carried by the currents and subsequently deposited at T1, illustrating that sedimentation at T1 results from both wave action and the influence of high current velocity.

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