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Numerical Hydrodynamic Wave Modelling Using Spatial Discretization in Brebes Waters, Central Java, Indonesia

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Abstract— **When the wave is moving toward the shoreline, hydrodynamic processes occurred in the waves that give an effect on the shoreline and its surrounding buildings. The process of erosion and accretion that occurred on Brebes coastal area induces certain impacts. The purpose of this study was to determine the pattern of hydro-oceanography and seabed morphology in coastal areas. Primary data obtained during field survey was employed in this study, which was processed using simulation models by applying spatial discretization method that is based on the finite volume equations to obtain the condition of waves, currents, sediment transports and tides. The results showed Brebes waters included in the category of shallow waters with slope topography, while the tidal type is a mixed tide prevailing semidiurnal. Waves were generated in the Northern Brebes then were moved towards the mainland until it deformed, leaving energy in the form of longshore current that goes into the area around the beach ridge. The time difference between high and low tide was influenced by the mass of estuary water supply from the sea as well as the mass of water from upstream to downstream. The high level of vulnerability in the coastal area requires the more effective and efficient treatment to prevent a negative impact on physical and social conditions.**

Keywords— **hydrodynamics; wave; current; sediment transport**

I. INTRODUCTION

The coastal region is a rich environment in term of biological and non-biological resources. This environment commonly used as a settlement, aquaculture, agriculture, and tourism. The high-intensity utilization and a lack awareness in conservation will result in a negative impact on physical and social conditions that would affect the region's vulnerability.

Climate change may cause changes in wind direction and speed, air pressure patterns and rainfall patterns that led to floods and droughts [5]. Nowadays, the global warming is not just an issue but has become a reality and as a warning for a living being existence. Based on the International Panel on Climate Change (2007), the average global surface temperature increased 0.74^0C in the late 19th century, and the earth's temperature will rise 4.5^0C. Rising of global surface temperatures causes the ice liquefaction of North and South Poles that trigger the sea level rise, characterized by widespread areas inundated by rob (flood). The enhancing of coastal activity and developing of city center nearby have a trigger to the coastal imbalance and land subsidence event [13].

The surface wave is one form of energy propagation that is usually caused by the wind blowing over the ocean [2]. At the time of the wave moves towards the shoreline, six events may occur, impact the shoreline and the buildings around it. These sixth events are refraction, diffraction, reflection, wave shoaling, wave dumping and wave breaking [1], [4].

Brebes has about 65.48 km of coastal area that in the year of 1983 was covered by mangrove with an area about 2,327 ha [9], but in 2008 only 257.11 Ha of mangrove remain. According to Department of Marine and Fisheries of Brebes District (2008) in 2000, erosion affected 789 ha of the coastal area and reached 640.45 ha in 2008. In the other hand, in 2000 accretion was occurred in the area of 310 ha, while in 2008 increased to 815.76 ha that was encompassed shoreline of 27.14 km. The number of erosion and accretion occurrence in this area becomes a process that very interesting to be studied because it deals with the coastal vulnerability that might affect its social and economic activities. The purpose of this study is to determine the pattern of hydro-oceanography and coastal morphology in Brebes coastal area.

II. MATERIALS AND METHODS

Primary data was collected in the study area from April until August 2016. The research method applied is a purposive quantitative, which has a specific purpose, detail work and based on calculations or measurements [6]. Tide was measured by Tide Master Valeport Automatic Tide Gauge for 30 days at coordinates 6, 782°E and 109, 035°N. Furthermore, the tide data was processed to obtain tidal harmonic constants that important to determine the MSL value and the tide type. Tidal range was obtained from the difference between high and low tide then the tidal analysis was done by the Admiralty.

The wave data is obtained by model, the numerical simulation conducted for 2 seasons (East and West season), that hydrodynamic model is using Spectral wave module and validated by the field tidal data to obtain the difference error of field condition and simulation.

To determine the water depth in Brebes, bathymetry survey was performed using a transducer and echo sounders at the sites. The position of the measured depth was connected to the GPS by applying the acoustic method on an Echosounder Echotrack CVM Teledyne Odom Hydrographic Single Beam. The tool transmitted the acoustic frequencies to the bottom of the ocean waters to get the real-time depth data [12]. The obtained bathymetry data is then analyzed spatially and mathematically.

III. RESULT AND DISCUSSION

A. Bathymetry

Data obtained from bathymetry measurements are raw data, which has not been corrected by transducer depth and tides. Raw data contains information about measurements time (date and time), measurement coordinated in (X, Y) and transducer depth.

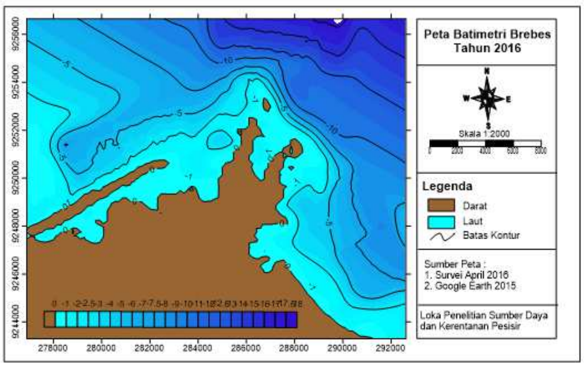

Fig. 1 Bathymetry map of Brebes district (source: Data Processing)

From the results of tide gauge measurements, it was obtained MSL value of 110 cm and Zo value of 119 cm. Chart datum value depends on the value of Zo, where Zo calculation is based on IHO standards as the international standard to calculate Chart Datum. The results of bathymetry raw data processing results in waters depths range of 0 – 18 m (Fig. 1). It has to be noted that the depth results are the water depths at the time of measurement, it is necessary for a reference to describe the condition of the seabed (Chart Datum). Chart Datum was used as the basis to determine the bathymetry [10].

In Fig. 3, it appears that the profile of the seabed of Brebes is shallow marine water with depths ranged between 0 – 18 m. Contour lines of Brebes seabed have a pattern that on a line with the shoreline. Waters depth gradually increase towards the offshore. The seabed topography, from the coastal plain to a depth of 15 m, tends to be flat with a slope of 12°. The waters depth cross-section profile can be seen in Fig. 2.

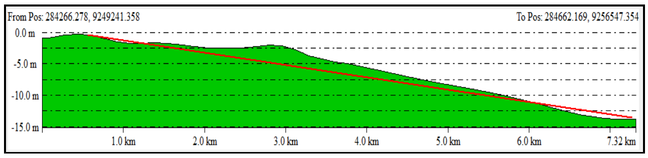

Fig. 2 Cross-section profiles

The area of bathymetry survey is 14,467.5 hectares that are divided into several different depths and spread evenly following the basic conditions of the waters, the depth distribution of Brebes can be seen in Table 1. A beach ridge can be found on the East side of Brebes waters, which its existence is influenced by the tide condition occurred in the study area. The type of sediment that found in the Western part is sand and clay in the North. According to [13] defined that the unstable coastline is caused by the presence of high sedimentation, the influence of tides, as well as the destruction of mangrove forests.

TABLE I
DEPTH DISTRIBUTION OF BREBES

Depth (m)	Area (Ha)
17.5-18	33.5
15-17.5	673.9
12.5-15	1047.0
10-12.5	1428.5
7.5-10	2151.3
5-7.5	2722.3
2.5-5	2458.0
0-2.5	3953.0
Total	14467.5

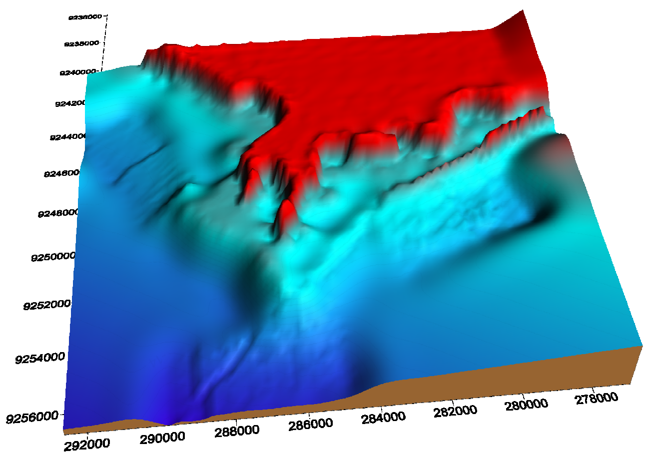

Fig. 3 Brebes seabed conditions

Generally, the seabed of Brebes can be visualized in three dimensions as shown in the Fig. 3. In processing the bathymetry, we implement kriging method that can be functioned as an exact interpolator or as a tool to make the seabed contour finer, depends on the parameters used [7].

B. Tidal

Based on admiralty calculation for 15-days tide data, we obtained Formzahl values (F) of 0.412. These results indicate that tidal type of Brebes waters is a mixed tide prevailing semidiurnal with M2 and S2 are dominant component. The type shows that in one day there are two high and low tides occurrence with different height and times.

The tidal type can be seen from the semi-diurnal tidal components M2 with the amplitude value 0.1384 and phase difference of 234.16°, and the S2 amplitude component of 0.1240 with the phase difference of 151.43°. Type of tide is relatively similar to the observations of tidal waters by [11] which states that the tidal type is a mixed tide prevailing semidiurnal, while the diurnal components K1, O1, P1 have a smaller value than the semidiurnal. Declination of the sun on the components is represented by the P1 value with the amplitude value of 0.0269 and 38.2° phase difference. In addition, the effect of the moon declination can be seen from the large O1 amplitude value of 0.0273 at 85.28° phase difference. Of tidal component are affected by the moon, the M2 represents semi-diurnal components, and O1 represents the diurnal component that has an amplitude and phase difference value greater than another tidal component. It can be assumed that the tide condition in the Brebes waters is strongly influenced by the moon movement. The different contours and topography of the seabed change the nature of the tidal [8].

Moreover, hydrographic and meteorological factors also affect the characteristics of the tides at certain location [3]. Mean Sea Level of Brebes waters represented by So components with a value of 109.7 cm. There is 3 referenced datum used in determining the tidal, 1) The median of tidal elevation, 2) the chart datum, and 3) the highest water level average. Table 2 below shows the sea level fluctuation value of Brebes waters.

TABLE II
SEA LEVEL FLUCTUATION VALUE

Component	Value (m)
Z_O	1.19
CD	-0.10
MLLWS	0.26
LAT	0.00
MHHWS	1.93
S_O	1.10
TIDAL RANGE	1.61
MLHWN	1.88
MLLWN	0.32

TABLE III
TIDAL CONSTITUENT VALUES OF BREBES WATERS

Constituent	A (m)	g(°)	Constituent	A (m)	g(°)
So	1.097	0	K1	0.081	38.02
M2	0.138	234.1	O1	0.027	85.28
S2	0.124	151.4	P1	0.027	38.02
N2	0.026	130.7	M4	0.006	158.6
K2	0.033	151.4	MS4	0.004	16.76

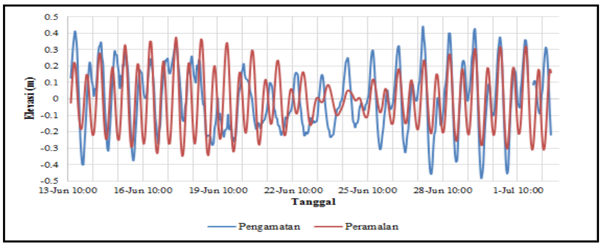

Fig. 4 Graph of tidal forecasting and field observation

The results of overlaid between observation data and tide forecasting during the neap tide show there is a deviation about 20 – 30 cm, while during the full moon (spring tide) the difference between observation and forecasting was only 10 cm. Tide observation data shows the time difference of high tide (low to high tide) are relatively shorter than the low tide (high to low tide). MRSE validation of high and low tide of 10.89% and 12.32%

C. Wind Distribution

One of the components that initiate the waves is the surface wind. Distribution of maximum winds occurrence in Brebes over past 11 years (2006 – 2016) is shown in Fig. 5 below

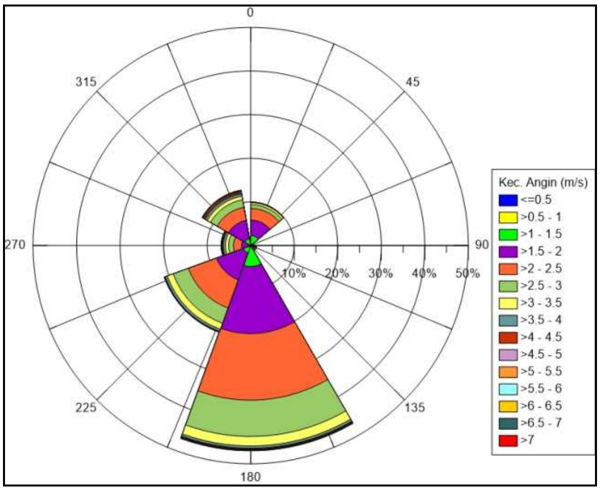

Fig. 5 Wind rose in Brebes 2006-2016

Wind rose graphs (Fig. 5) shows that the dominant winds move from the North to the South with speeds ranged from 0.5 to 7.2 m/s. As wind rose graph for every season for the last 10 years are displayed in Fig. 6 below.

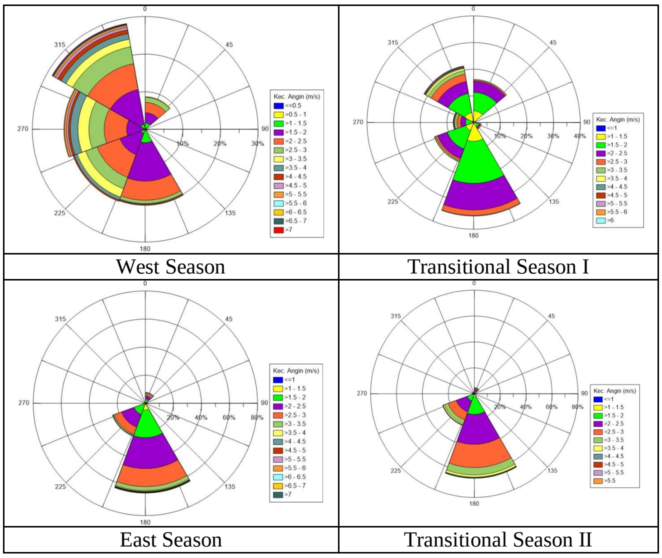

Fig. 6 Wind rose for each season in last 10 years

Fig. 6 shows the dominant wind direction for every season during 2007 – 2016. The dominant wind in West Season (December – January) moves from the Southeast toward the Northwest with speed of 0.7 m/s – 7.2 m/s. The dominant wind during the Transitional Season I (February – May) blows from the Southwest towards to the South with speed ranged 0.5 m/s – 6.2 m/s. The dominant wind during the East Season (June – August) moves to the south with a speed of 0.5 m/s – 7.2 m/s. The dominant wind during the Transitional Season II (September – November) blows from the West towards South with a range of speed of 0.7 m/s – 5.7 m/s. The dynamics of monsoon wind trades system contribute to momentum transfer and water mass transformation [14].

D. *Significant Wave*

To view the hydrodynamic processes that are occurred in the Brebes waters, the observation was conducted in 3 locations as presented by the following Fig. 7.

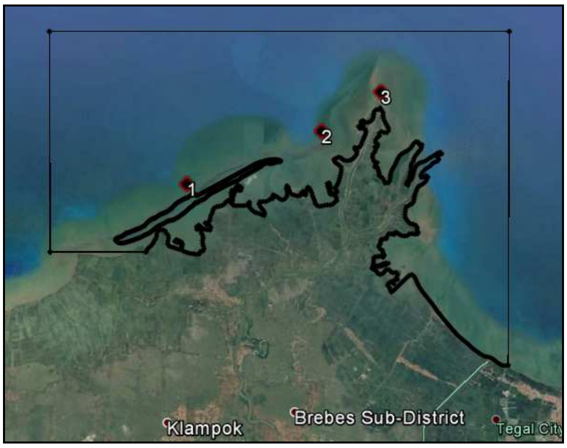

Fig. 7 Observation point

The 1st point was selected because it is in front of the beach ridge and has a high intensity of sediment transport, the 2nd point is an extended area of mangrove that can be considered as the wave attenuation area, while at the 3rd point there is a Pemali River estuary as the end location for accumulated sediment from the highland.

In the west season, significant wave height is 0 to 0.73 meters in the high tide condition. The significant wave height is getting smaller when it approaches the mainland and in the beach ridge surroundings due to the waves deformation. Deformation defined as the refraction of waves that leads the wave energy to reduce linearly that also reduce the significant wave height as well.

In the Northern of beach ridge, the 1st point, Hs value of 0.56 meters indicates this location is a prone area to the effect of waves and potential area of sediment transport around the beach ridge. At the 2nd point, in the Eastern part of beach ridge, wave height reaches 0.46 meters. This area is the most potential place where the sediment transport between land and sea occur. The last observation point (3rd point) shows that the significant wave height at Pemali River's mouth is up to 0.53 meters.

At the low tide period, the height of significant wave ranged from 0 to 0.71 meters; it can be said that the wave energy is higher at high tide than low tide. In the Northern part of beach ridge, we found that the significant wave high about 0.51 meters. High waves of 0.41 meters occur at point 2 and in Pemali River mouth, at the low tide, the wave reaches 0.48 meters high. Wave propagation direction is not much difference between high and low tide, that is dominant to the South and Southeast. Waves were generated in the Northern Brebes then were moved towards the mainland and deformed then, leaving energy in the form of longshore current that goes into the area around the beach ridge.

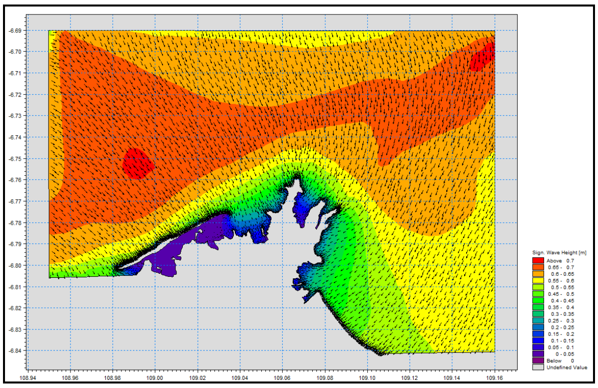

Fig. 8 Profile of significant wave at high tide in West Season (December-January)

Differences in Hs values at each sampling point is shown in Fig. 9 till Fig. 12. Hs value reached 0.56 meters, 0.46 meters and 0.53 meters at point 1, 2 and 3, respectively. The wave height was reduced in the Southern of beach ridge.

At point 1, Hs value is inversely proportional to Ts which means the higher the propagation, the smaller the periods. The required period to form a full wave at the 1st point is ranged between 4.89 to 4.92 seconds. While at the 2nd, Ts ranged from 4.83 to 4.97 seconds. And at the 3rd point, Ts values ranged from 4.85 to 4.94 seconds. It can be said that the wave energy is weaker when it approaches the mainland.

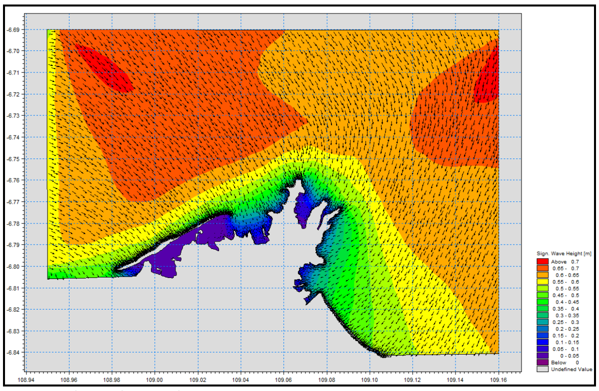

Fig. 9 Profile of significant wave at low tide in West season (December-January)

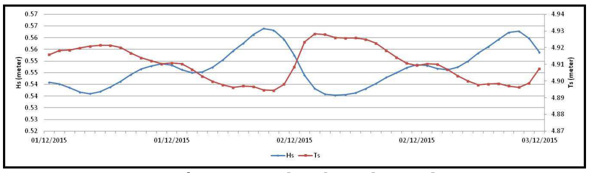

Fig. 10 Significant wave height and period in point 1

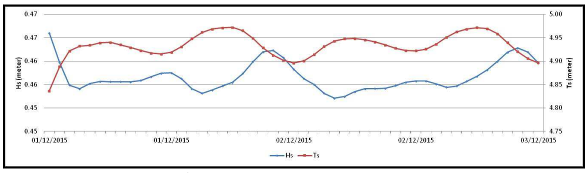

Fig. 11 Significant wave height and period in point 2

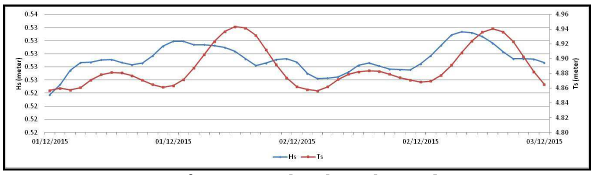

Fig. 12 Significant wave height and period in point 3

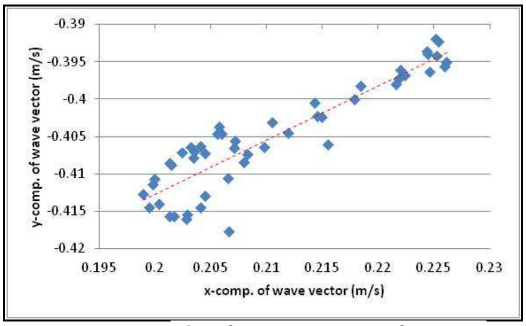

Fig. 13 Scatter plot of wave components for point 1

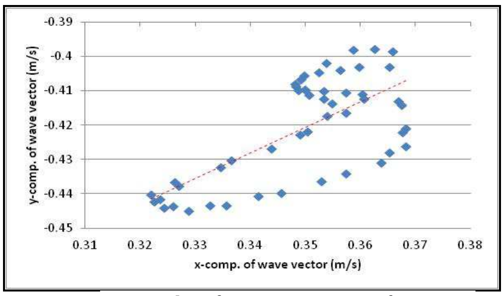

Fig. 14 Scatter plot of wave components for point 2

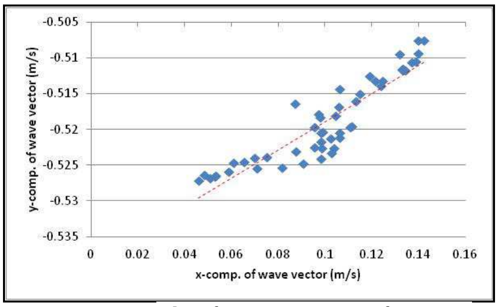

Fig. 15 Scatter plot of wave components for point 3

The velocity of the waves, in x and y directions, for each observation point is shown in Fig. 13 to the Fig. 15. Those graphs showed that negative wave dispersion happened at all points. Dispersion graph generally is depended on several parameters such the wave number, the gravity acceleration, and the depth of the water.

In the east season, the modeled significant wave height ranged from 0.0 to 0.711 meters on high tide conditions. In the Northern part of the beach ridge (Point 1), Hs value of 0.56 meters makes the area vulnerable to the wave effect and the potential area of sediment transport occurrence around the beach ridge.

At point 2, located in the Eastern part of beach ridge, wave height reaches 0.45 meters, that is a potential area where the sediment transport between land and sea. The significant wave height at the Pemali River mouth (point 3) up to 0.52 meters.

At the time of low tide conditions, the significant wave height ranged from 0 to 0.714 meters, that the wave energy in this low tide stronger than the high tide. In the same condition, the significant wave height in the north of the beach ridge was 0.53 meters.

High waves occur at point 2 which reached 0.45 meters and at the Pemali River mouth was about 0.52 meters. The direction of wave propagation is not much difference between the condition of the high and low tide that is dominant to the South and Southeast.

Differences Hs values at each sampling point are shown in Fig. 16 to 20. In point 1, Hs value reached 0.56 meters; point 2 reached 0.45 meters and 0.52 meters at point 3. The wave height was reduced in the South region of the beach ridge.

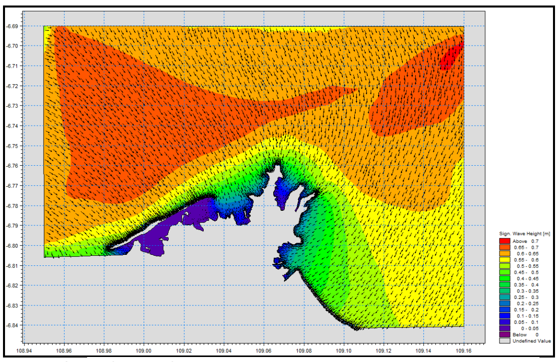

Fig. 16 *Profile* of significant wave at high tide in East Season (June – August)

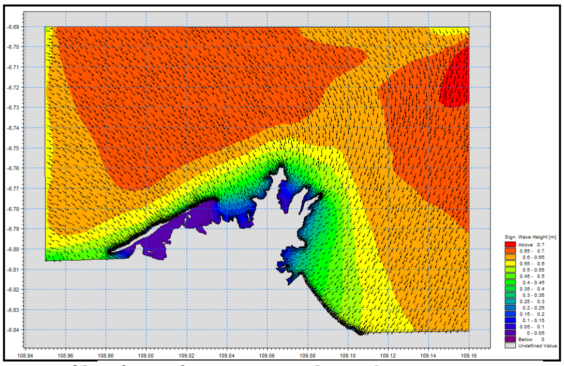

Fig. 17 Profile of significant wave at low tide in East Season (June – August)

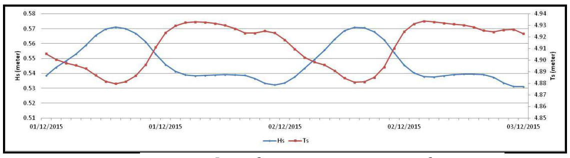

Fig. 18 Scatter plot of wave components for point 1

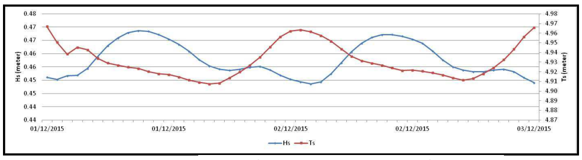

Fig. 19 Scatter plot of wave components for point 2

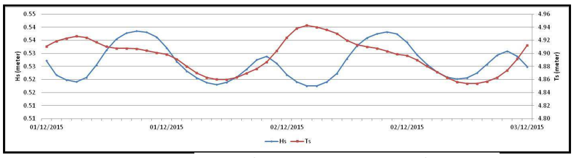

Fig. 20 Scatter plot of wave components for point 3

At point 1, Hs value is inversely proportional to Ts, thus the high the propagation the lower the period. The required period to achieve a full wave in point 1 ranged from 4.87 to 4.93 seconds, while at point 2 ts values ranged from 4.91 to 4.96 seconds.

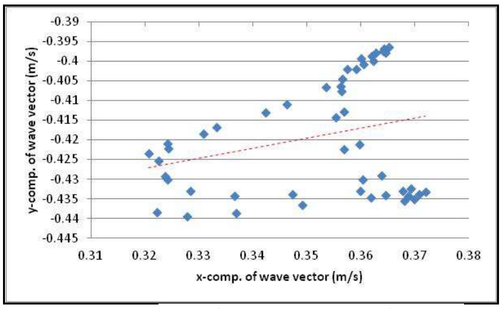

Fig. 21 Scatter plot of wave components for point 1

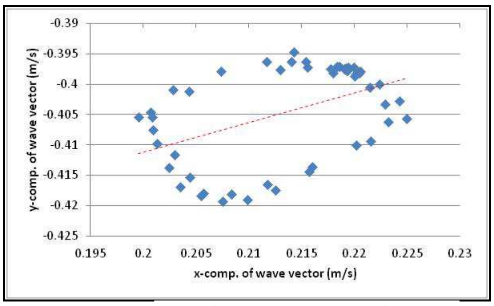

Fig. 22 Scatter plot of wave components for point 2

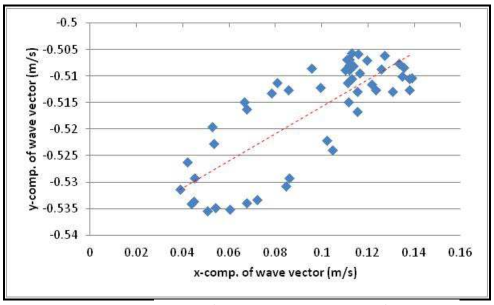

Fig. 23 Scatter plot of wave components for point 3

At point 3 Ts values ranged from 4.85 to 4.94 seconds, means the wave energy weaker when approaching the mainland. The velocity of the waves, in x and y directions, for each observation point is shown in Fig. 21 to Fig. 23.

The negative dispersion of the wave appeared at all three points. The dispersion graph generally depended on several parameters such as wave number, the acceleration of gravity and depth of water.

At point 1 the water depth is the deepest point than surrounding, so the wave group velocity and wave dispersion are higher than the others, in point 3 the water depth becomes shallower so that the frequency dispersion is also weakened.

IV. Conclusion

Brebes District waters categorized as shallow water, which depth between 0 – 18 m. We found that the seabed slope of 12° along 7.9 km from the shoreline, which classified Brebes seabed as a ramps slope. The time difference between high and low tide influenced by the estuary water mass supply from the sea and the water mass from up to downstream.

In the area where the water depth greater than a half the wavelength, in the deep sea, the waves propagate without being influenced by the seabed. But in the transition and shallow zone, the wave is affected by the seabed topography. In this area, part of the wave crest in the shallower water propagates at a slower speed than part of the water in the deeper depth. As a result, the wave crest line turned and tried to align with the seabed contour.

In general, headland area experiencing the erosion otherwise the bay area experiencing deposition. The deposition appearance in the bay due to the small wave. Waves that propagate toward a barrier, such as a beach or the coastal structure, part or the whole wave will be reflected back.

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