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OCEAN WAVES ANALYSIS FOR SUBMERGED BREAK WATER PLANNING TO OVERCOME THE DAMAGE OF TIMBULSLOKO COASTAL AREA, DEMAK, INDONESIA

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Abstract– Timbulsloko Demak is one of the densely populated areas in Central Java Province which has a complex problem of erosion and coastline changing of up to 100 m per year. This erosion has reached an area of 938.73 hectare which is caused by ocean waves to the coast. The purpose of this researchis to determine the height and the depth of breaking waves. Other than that, we also are determined the most optimal design of submerged breakwater to protect the coast as a consideration in planning the construction of a coastal protection structure in the waters of Timbulsloko, Demak, Iindonesia. Wave modeling was used as a mathematical approach. Based on the data processing, it is known that submerged breakwaters can be planned to be built at a minimum depth of breaking waveranging from 1.5 to 2.5 meters and the maximum breaking wave in the depth ranging from 1.8 to 3.8 meters with a breaking wave height ranging from 1.2 to 2.5 meters. While, the most optimum submerged breakwaters used as an alternative building in reducing wave height is submerged breakwater with a building height of 75% of the water depth.

INTRODUCTION

Nowdays, there are some areas in Indonesia that experience severe coastal erosion. One of them is inDemak. Demak is located adjacent to the Java seas, approximately 26 km from Semarang, the capital city of Central Java (Damastuti and Groot, 2018). One of the most vulnerable areas in the coastal area of Demak is Timbulsloko village. Timbulsloko village is one of the villages located in the coastal of Sayung, Demak, Central Java, Indonesia which is bordered with Bedono Village (Astuti et al., 2018). Timbulsloko is a dynamic area and vulnerable to the threat of environmental degradation (Perdana et al., 2018).Timbulsloko village has 462.50 hectare of land area, with 3.5 kilometers of coastal line since it is geographically located at coastal zone and directly bordered with Java Sea. Administratively, this village is divided into four sub-village consisting of Wonorejo, Karanggeneng, Bogorame and Timbulsloko. Timbulsloko is 8 kilometers away from Sayung District office, and 17 kilometers from the capital of Demak Regency (Purnaweni *et al*., 2018).

In the northern coastline of Java Island, the total damaged of thecoastal area has reached 6,566.97hectare with the most severe damagefound in Sayung District, Demak Regency, Central Java Province (Purnaweni *et al*., 2017) which covers 935.18 hectare area.The changing of coastal area has influenced by several factors of natural mechanism and has rapidly affected by human activities (Hawati *et al*., 2017).There are some conversions of agricultural land and mangrove areas that caused the Timbulsloko area to erode. This situation is getting worse by the expansion of Tanjung Mas Port, land subsidence and sea level rise. In 2002,there was an erosion of 145.5 hectare and increased to 758.3 hectare in 2005. Satellite observations show that between 1999 and 2006 coastline changes due to erosion had reached 771.4 hectare (Suripin *et al*., 2017).

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The construction of coastal buildings located in Demak Waters to mitigate the erosion has been developed such as in the form of hard, soft and hybrid that available to mitigate the erosion (Kristiningsih *et al*., 2018). Some structures that are also considered to protect the coast of Demak Waters aregroynes and hybrid engineering (HE) structures to reduceocean waves (Suripin*et al*., 2017). Since HE was applied in 2012, sea water didn'tflood the settlement. However, these buildings will be sunk by sea water parameters. In order to anticipate this condition, several researches of submerged breakwaters were made. This research is to study the wave height at before and after the planned breakwater so,it can optimally reduce the wave energy before reaching to the coastline.

Ocean waves play an important role in the coupled ocean-atmosphere interactions (Rutgersson *et al.*, 2010; Cavaleri *et al.*, 2012; Patricola *et al.*, 2016). Ocean waves that areaffected by wind are called wind sea. Once these waves propagate away from their generation area, out-speeding the local wind and no longer receiving energy from it, they are called swellwaves (Semedo *et al.*,2018).Many specific problems in the coastal zones require an accurate description of the wave field and knowledge of wave parameters (Albarakati and Aboobacker, 2018).

Submerged breakwater is one kind of offshore structure which is widely used in waterway. Its main functions are wave dissipation, sand barrier and river diversion (Lie-hong *et al*., 2017). There are some new research findings relating to the wave propagation of submerged breakwater planning (Ting *et al*., 2016; Driscoll *et al*., 1992; Wang *et al*., 2011). Therefore, the prediction of ocean wave characteristics plays a crucial role in the assessment on marine, coastal and harbour structures and model testing (Kumar *et al*., 2018). The interaction between waves and marine structures is one of the most challenging problems in ocean engineering (Wang *et al.*, 2018).

MATERIALS AND METHODS

Materials

The materials used in this research consisted of main data which is includedocean wave data and secondary data i.e. batimetry data of Timbulsloko waters (in 2017 recording), LPI map (in the scale of 1: 250,000 for Demak area), wind data of Semarang City (from 2007 to 2017), tidal data (in July 2017) and coastline data from Geoeye Satellite Image (in 2018 recording). The research was conducted directly in the field from 23rd to 27th July 2017 in Demak waters.

Methods

Ocean Wave Data

The measurement of ocean wave data were done by the observation at the depth of 12 meters from the sea level in the waters of Demak. The determination of ocean wave measurement point was consideredinthe open water locations, which was not affectedby the wave propagation. This location is an area where the ocean wave still is not transformed. The location point of ocean wave data measurement is shown in Figure 1.

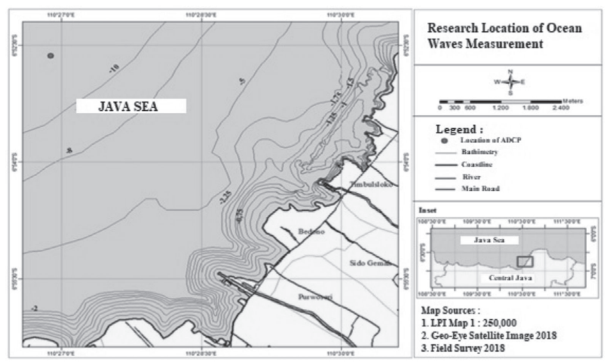

Fig. 1. Location of ocean wave data measurement

The measurements of ocean wave were conducted from 23rd to 27th July 2017 by usingADCP that was setfrom 10 am (on 23rd July 2017) to 4 pm (on 27th July 2017). The results obtained consisted of significant wave height (Hs) and significant wave period (Ts). The direction of the coming wave is based on the direction of wind in this location.

Then, the ocean wave data fromthe field observation were processed to obtain the representative wave height (H_{max}) and periods (T_{max}). The breaking wave heighs are calculated with the equation1.

$$\frac{Hb}{H'0} = \frac{1}{3,3\,(\frac{H'0}{L0})^{\frac{1}{3}}} \quad ..(1)$$

where : H_b is the breaking wave height, H'_0 is ocean wave height (in the equivalent forms) and L_0 is the wavelength in the deep ocean. The depth of breaking waves (dB) can be determined by using

Equation 2.

$$\frac{dB}{Hb} = \frac{1}{b\,(a\,\frac{Hb}{gT^2})} \quad .. \quad (2)$$

where :

$$a = 43{,}75\,(1 - e^{-19\,m}) \quad \text{and} \quad b = \frac{1{,}56}{(1 + e^{-19{,}5\,m})}$$

d_B is the depth of breaking wave, H_b is the breaking wave height, *g* is the gravity acceleration of earth and T is the wave period (Triatmodjo, 1999).

The wave propagation analysis was solved by using the BOUSS2D model for mathematical approach. Thedata input on the model is the result of ocean wave forecasting by using wind data.

Wind Data

Wind data used were accessed fromBMKG station for the duration in every 3 hoursfor 11 years (2007-2017). These data consisted of the value of wind speed and direction.The wind data used were classified by seasons, i.e. west season, transition 1, east season and transition 2. Then, the data were presented in the form of wind distribution to know the distribution of dominant wind.

Other than that, wind data were used also to forecast the ocean wave (Alifdini *et al*., 2018). In this research, the ocean waves were forecastedby using DNS method (Sugianto, 2010)to get the value of Hs and Ts. The value of Hs and Ts can be calculated with Equation 3 and 4.

$$Hs = 0{,}0016\,U^2 + 0{,}0406\,U \quad .. \quad (3)$$

$$Ts = 0{,}15\,U + 2{,}892 \quad .. \quad (4)$$

where : Hs is significant wave height (m), Ts is significant wave period (s) and U is the wind speed (knots)(Sugianto, 2017).

Bathymetry Data

The bathimetry data obtained from Map of Coastal Environment Indonesia (LPI)in Demak area (in the scale of 1: 250,000). The bathymetry map was used as an input to create the model ofocean wave.

Tidal Data

The tidal data were processed by using Admiralty Method to obtain the value of tidal harmonic constants i.e. M2, S2, K1, O1, N2, K2, P1, M4 and amplitude (A). From these constants, we obtained MSL (Mean Sea Level), HHWL (Highest High Water Level), LLWL (Lowest Low Water Level) and tidal type. In addition, this datawere also used to correctthe bathymetry data.

Submerged Breakwater Data

The dimension of the building used is 150 meters long and 3 meters wide that parallel to the coastline. The width of the gap used between the buildings is 30 meters with 11 buildings. This breakwater was placed at a depth of 2.37 meters above the surface of the water (based on the depth of a breaking wave in the transition 1 season). The breakwater building used is a sinking structure so it does not appear on the surface of the water. The building height used is 75% of the water depth, which can produce the most effective wave damping.

Data Verification

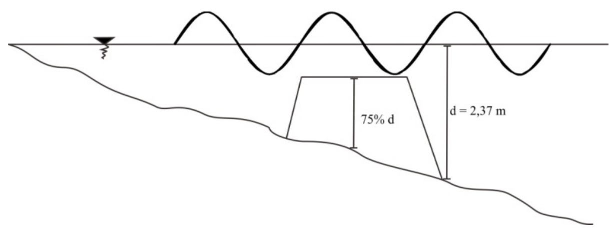

Fig.2. The Ilustrationof Submerged Breakwater

The ocean waves data from the forecasting of wind data were verified with the ocean wave data from the field measurement. The verification type used areCost Function(CF) and Mean Relative Error (MRE) method. OSPAR Comission (1998) in George et al. (2010) stated that the CF criteria used are if CF value more than 1, so the data obtained isvery good. If CF value in the range from 1 to 2, the data aregood. If CF value from 2 to 3, so the data areacceptable and if CFvalue is 3, the data obtained is bad. The value of CF can be calculated by the equation 5.

$$CF = \frac{1}{N}\sum_{n=1}^{N}\frac{|Dn - Mn|}{\sigma_D} \quad .. \quad (5)$$

where :N is the number of dataobservation, *n* is the data at the desired amount, D is the observed data, M is the model data and óD is the standard deviation. The standard deviation value can be calculated by the equation 6.

$$\sigma_D = \sqrt{\frac{1}{N}\sum_{n}^{N}(D_n - \bar{D})^2} \quad .. \quad (6)$$

where: $\bar{D}$ is the average value of the data observation.

Meanwhile, according to Rianto (2004) in

Purwanto (2011), the relative error and mean relative error correction can be calculated using the equation 7 and 8.

$$RE = \frac{|X-C|}{X} \ x\ 100\% \quad \text{.. (7)}$$

$$MRE = \sum_{0}^{n} \left|\frac{RE}{N}\right| \quad \text{.. (8)}$$

where :RE is a relative error, MRE is the average of relative error, X is the field data, C is the simulated data and N is the amount of data.

RESULTS

Field Data Measurement of Ocean Waves

The field data measurement of ocean waves is presented in Figure 3.

Based on the field measurement data, the maximum, minimum and averageof height and period of ocean wave are 0.22 meter and 6.00 second, 0.05 meter and 3.80 second, and 0.10 meter and 4.43 second, respectively. These results are presented in Table 1.

From the value of maximum ocean wave height and period, we obtained the height and depth of breaking waves. The results are presented in Table 2.

Table 2. The Data of Breaking Wave

Parameters			
H (m)	T (s)	Hb (m)	db (m)
0.22	4.1	0.31	0.391

Based on the maximum value of height and the period of ocean waves, the depth of the waters and the value of the coastal slope, the ocean wave in Timbulsloko waters broke at a depth of 0.40 meter from the sea level with the breaking wave height of 0.31 meter.

Ocean Wave Forecasting

Ocean wave forecasting by using DNS method (Sugianto, 2010) is used to determine the value of wave transformation by using wind data. The wave parameters obtained are in the form of wave height and wave period. The results are presented in Tables 3 and 4.

Table 1. Ocean Wave Heights and Periods in Sayung Demak based on Field Measurement

Hs (meter)			Ts (second)		
H max	Hmin	Haverage	T max	T min	Taverage
0.22	0.05	0.10	6.00	3.80	4.43

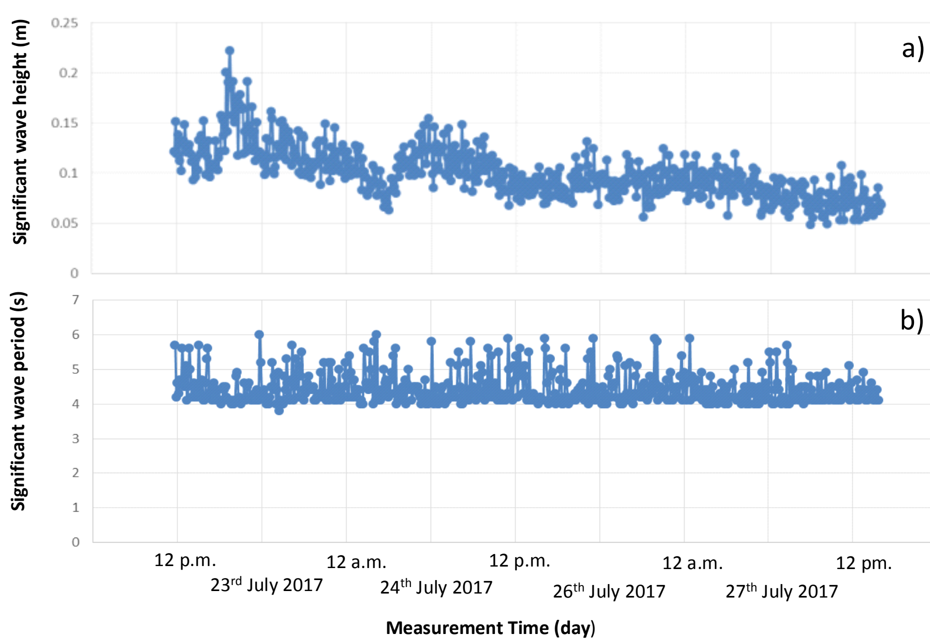

Fig. 3. Graph of Ocean Waves of Field Measurementa) Significant Waves Heightand b) Significant Wave Periods of Sayung Demakfrom 23rd July to 27th July 2018

Table 3. Forecasting of significant wave heights for the Data of 11 years (2007-2017)

Season	H max (m)	H average (m)	H min (m)
West	2.66	0.35	0.04
Transition I	2.26	0.30	0.04
East	2.26	0.30	0.04
Transition II	2.66	0.34	0.04

Table 4. Forecasting of significant wave periods for the data of 11 years (2007-2017)

Season	T max (s)	T average(s)	T min (s)
West	7.39	3.85	3.04
Transition I	6.94	3.75	3.04
East	6.94	3.75	3.04
Transition II	7.39	3.84	3.04

Wind Distribution

The wind distributions was analyzed by using the wind data for 11yearsthat obtained from the BMKG station in Indonesia. These data are grouped per season that are presented in the form of windroses per season (based on the speed and direction of the wind). Diagram of wind roses are presented in Fig. 4.

Wave Data Verification

Wave data that obtained from the forecasting by wind data were verified by ocean wave data from field measurement by comparing them with CF (Cost Function) and MRE (Mean Relative Error). The results of CF and MRE are presented in the Table 5.

Table 5. Verification of Ocean Waves by using CF and MRE

Verification Parameters	Hs (m)	Ts (s)
CF	0.09	0.0053
MRE (%)	3.74	0.93

Based on the calculation of CF (Cost Function), the value of a significant wave height is 0.09 m and a significant wave period is 0.0053 sec. So both values are categorized as very well because the values are more than1. In addition, based on the MRE calculation, the value of significant wave height is 3.74% and 0.93% for the significant wave period. These value can still be used as an input data because the error value is not more than 50%, as Purwanto (2011) stated that the data generated from the computation is not always the same as the data

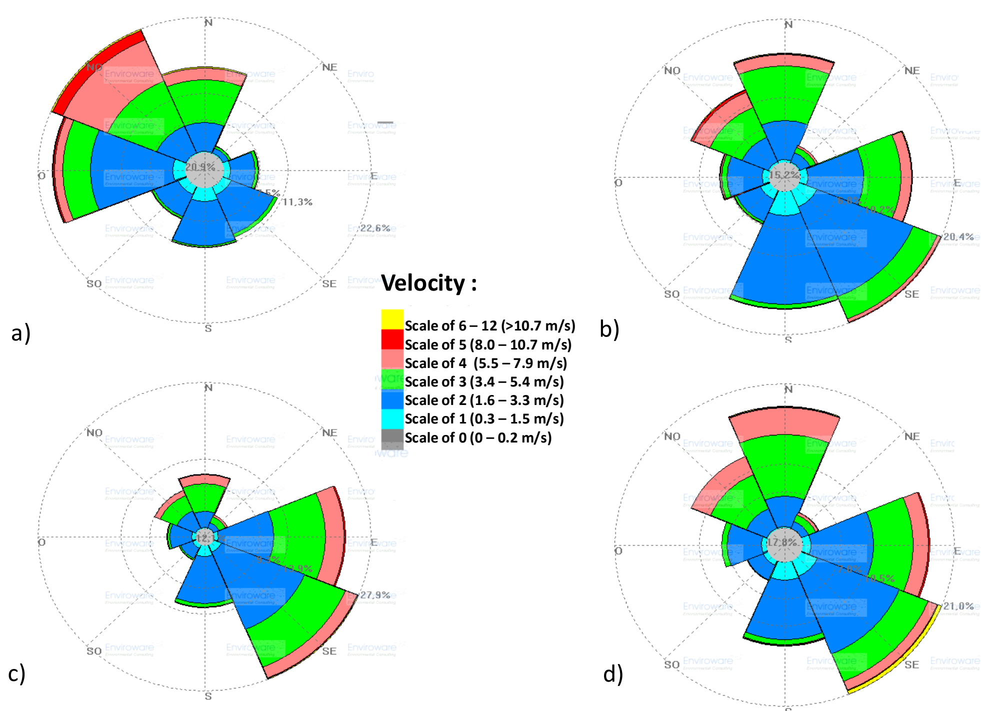

Fig. 4. Wind Roses of (a) The West Season (b) Transition 1 (c) East Season (d) Transition 2 of 2007-2017

generated from the field, but will not be a problem if the relative error obtained does not exceed 50%.

Analysis of Breaking Waves

In the breaking wave calculations, we used wave height and period of 10 percent above (H_{10} and T_{10}) for each season. The results consisted of wave directions, breaking wave height (Hb) and breaking wave depth (db) which is presented in Table 6.

Table 6. Calculation of Height and Depth of Breaking Waves

Season	Direction	Hb (m)	db min (m)	db max (m)
West	North West	2.55	3.22	3.82
Transition 1	North	1.88	2.37	2.81
East	North East	1.22	1.53	1.83
Transition 2	North	1.96	2.48	2.95

Wave Model Simulation

Simulations of ocean wave model were performed on four seasons, i.e. west season, transition 1, east season and transition 2. In west season,there are two conditions, i.e. wave origin from the northwest and from the west. In the transitional 1 and transitional 2 seasons, the wave comes from the same direction, so it only takes one modeling for these transition season. While,in the east season, the waves come from the northeast.

The submerged breakwater layout in Timbulsloko Demak waters is based on the calculation of breaking wave depth. The wave break at a distance of 1200 meters from the coastline and has a wave height of 1.8 meters. The results of the ocean wave simulation model with the existence of submerged breakwater are presented in Figure 5. In addition, the efficiencies of submerged breakwater are presented in Table 7.

DISCUSSION

The Measurement of Ocean Wave in TheField

Based on the results of the the field survey, the maximum of wave height obtained is 0.22 meters with a maximum wave period is 6 seconds. Thesevalues are quite small because the wave measurements were carried out in the east season

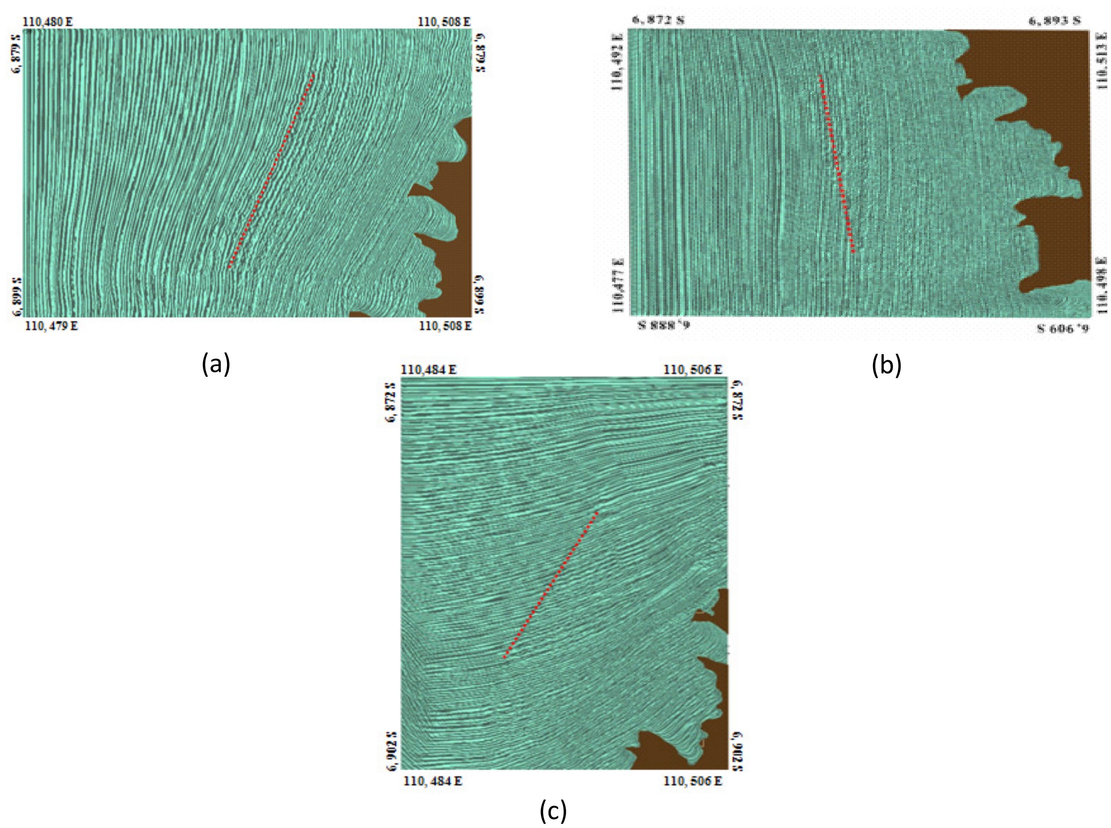

Fig. 5. Wave modelling with the existence of submerged breakwater. a) In the west season from west direction, b) In the west season from northwest direction and c) Intransition season from north direction.

Table 7. The Efficiencies of Submerged Breakwater in the Waters of TimbulslokoDemak

Scenario	Seasons	H before breakwater	H after breakwater	Efficiencies (%)
Submerged breakwater	West from west direction	1.21	0.97	19.81
	West from northwest direction	1.28	0.97	24.82
	Transition	1.24	0.74	40.57

where the wind velocity blows in the Java Sea is relatively smaller than in the west season. These result is appropriate with Bayong (2004) in Anggraeni (2016) who stated that in the west season, the wave height value is higher than in the other three seasons. The wind velocity that blows in the west season will be stronger when compared to other seasons.

While based on the relative depth, these waters are divided into the category of transition or medium waves. The value of comparison between water depth d and wavelength L is 0.46. This is appropriate with the statement of Triatmodjo (1999) which stated that the medium water waves have a relative depth of $0.05 < d/L < 0.5$.

Based on the calculations, the value of breaking wave height is 0.31 meters with the depth of breaking waves at 0.4 meters. This value is quite smallbecause the wave data were taken in July 2017 where the moon is in the east season that has a small wind power.

Wind Data Distribution

The distribution of wind data are shown in the form of windrose. The wind velocities in the east and transitional seasons are a relatively small compared to the west season because the dominant wind is coming from the south. While, the wind direction from the south is not used in the waves forecasting because the wind blows from the mainland (not generating waves).

Ocean Waves Forecasting

The results show that the highest significant wave height is on the west season. This is because the wind velocity that blows from the west is stronger compared to the wind in other seasons. This proves that wind speed will affect the formation of ocean waves. Triatmodjo (1999) explained that one wave generator is wind, where a stronger wind will produce larger waves as well.

Analysis of Breaking Wave

Based on the results, the highest breaking wave happen in the west season of 2.55 meter. The depth ofbreaking wave is ranging from 3.22 to 3.82 meter. This condition is due to the large input of wave height values from the value of wind, where the wind in the west season blow stronger than in the east season and transitional season. This is appropriate by the research conducted by Bayong (2004) in Sugianto (2010) that due to the atmospheric circulation pattern, the wind velocity that blows in the west season will be stronger than in other seasons. In addition, breaking wave conditions also depends on the slope of the coast. More sloping a watershed contours, the more waves will break from the shoreline. The wave will break near the shoreline if the waters have a steep slope.

Simulation of Wave Model with The Consideration of Submerged Breakwater

In the west season, the coming directions of waves are from the west and northwest, where the wavesheight decreases about 0.3 meters. From the transitional season, the direction of the waves come from the north. The waves that hit the building will be reduced about 0.5 meters. But at the outside of the building the wave is still seen big enough to enter the mainland due to the location of submerged breakwater which is located too far. Observing from the value of efficiency, both of the west season and the transition season has a efficiency value that relatively small. Similarly, in the east season, due to the wave high input in the east season is small enough, the waves do not spread until the building. So, the building will have a higher efficiency value compared to the west season and the transition season. Although, submerged breakwaters do not break the waves on a large scale, it can reduce the spread of waves to the mainland. So, based on the calculation of the depth of the breaking wave, the development and location of submerged breakwater in TimbulslokoDemak waters quite effectively to reduce the waves. This is appropriatewith the statement of Ghipari *et al*. (2012) that the comparison of coastal morphology in before and when the submerged breakwater exist, the submerged breakwater is successfully in suppressing erosion rates than without submerged breakwaters.

CONCLUSION

Based on some considerations, the best plan is submerged breakwaters should be placed at a depth of breaking wave about 2.37 meters with the height of breaking wave about 1.88 meters. In addition, the best design of submerged breakwater is the height of building of 1.125 meters with a gap between buildings is 30 meters. The average efficiency of this building is 73.23% of wave reducer.

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