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Original Article

Tide Influence Vertical Pressure Distribution of Wave

Tommy Jansen

Department of Civil Engineering, Sam Ratulangi University, Manado, Indonesia.

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Abstract - *This study aims to determine the vertical pressure distribution of waves when tides occur simultaneously with ocean waves obtained by wave forecasting based on wind data. Changes in water level elevation due to tides coupled with waves can impact the occurrence of abrasion when the wave energy is large. The research was located in the Manembo-nemboGirianbeach Bitung of North Sulawesi. It begins with data collection in the form of bathimetric data, tidal data, and wave forecasting based on wind data at the research site. Tidal data is based on data from Lantamal VIII Manado; wind data is sourced from Bitung BMKG data. The pressure obtained on the wave is the summation of the hydrostatic pressure and the hydrodynamic pressure. The results of the simulations in the study showed that tidal waves working together with waves obtained from wave forecasting based on wind data would increase the magnitude of the wave's vertical pressure distribution. Based on the case of a comparison between wind wave and wind combination tidal, the wave pressure was obtained at 11.662 t in the crest and 2.607t in the trough of wave affected by wind, and 45.34t in the crest and 2.918t in the trough of wave combination tidal. It indicates that the tide can enlarge the vertical pressure distribution of waves.*

Keywords - *Tides, Wave pressure, Wind wave, Wind combination tidal.*

1. Introduction

Tides are fluctuations in sea level due to the force of attraction of objects in the sky, especially the sun and the moon, against the masses of seawater on earth. The attraction forces of these sky objects are the forces of tidal generation. The tides in the process result in changes in sea level.Sea level are always changing at all times. Therefore an elevation is needed based on tidal data, which can be used as a guide in planning a coastal building. Waves in the sea can be divided into several kinds that depend on the generation style. The wind wave arose from the blowing wind on the sea's surface. Wind waves are the most important in coastal engineering among the several waveforms. Natural waveforms are generally complex and difficult to describe mathematically because they are not linear, three-dimensional, and have random shapes. The simplification of the fact is in the presence of the Airy wave theory. Given the lack of wave data, wave forecasting from wind data is often carried out. (Triatmodjo,1999)

The Girian coastal area of North Sulawesi is an area that is intensively used for human activities. The intensity of tidal currents relative to the flow of seawater waves in a geometric configuration of a coast determines the effect of tides on rising and decreasing sea levels. As a result, the tides and waves generate forces in the water column, such as wave pressure. Other forces, such as wind stress and other meteorological forces, can be important modification factors specifically to a condition in a coastal region.

It can be formulated problems in this study as follows:

Tidal contributions to wind waves can cause damage generally to coastal buildings; there is an increase in wave intensity in wind waves due to tides.

A hindcasting method is a technique of forecasting upcoming or occurring waves using wind data from the past.

Wind data can be used to estimate the height and period of waves at sea.

The wind blowing greatly affects the occurrence of waves in the sea. In wind-water areas, the transfer events of wind energy occur to water. The originally still water surface will be disturbed, and small wave ripples will rise above the water surface due to the tension caused by the wind speed on the sea surface. As the wind speed increases, the ripples will become large, and eventually, waves will form if the wind continues to blow. The longer the wind blows, the greater the waves form. Wave hindcasting will estimate the wave's height (H) and period (T) due to winds of a certain magnitude, direction, and duration. Wave hindcasting is intended to transform wind data into wave data. The wave forecasting method can be distinguished as deep sea wave forecasting and shallow sea wave forecasting. The shallow sea forecasting method considers the friction factor between the motion of the water and the seabed to reduce the height of the waves formed.

In contrast, the seabed affects the deep-sea forecasting method, so the waves formed are not affected by the state of the seabed. Using tidal data for the benefit of scientists, such as the construction of buildings built in offshore waters and by the beach, requires tidal data in the form of sea levels position values like Mean Sea Level (MSL), Lowest Low Water Level (LLWL) and Highest High Water Level (HHWL). Mean Sea Level calculation analysis can be done harmoniously using the Admiralty method.

2. Research Location

The research location is on the Manembo-nemboGirian beach, Bitung City, North Sulawesi, in coordinates about $01^0$25'45.72" N- 125º07'40.69" E. The location can be shown in Fig.1.

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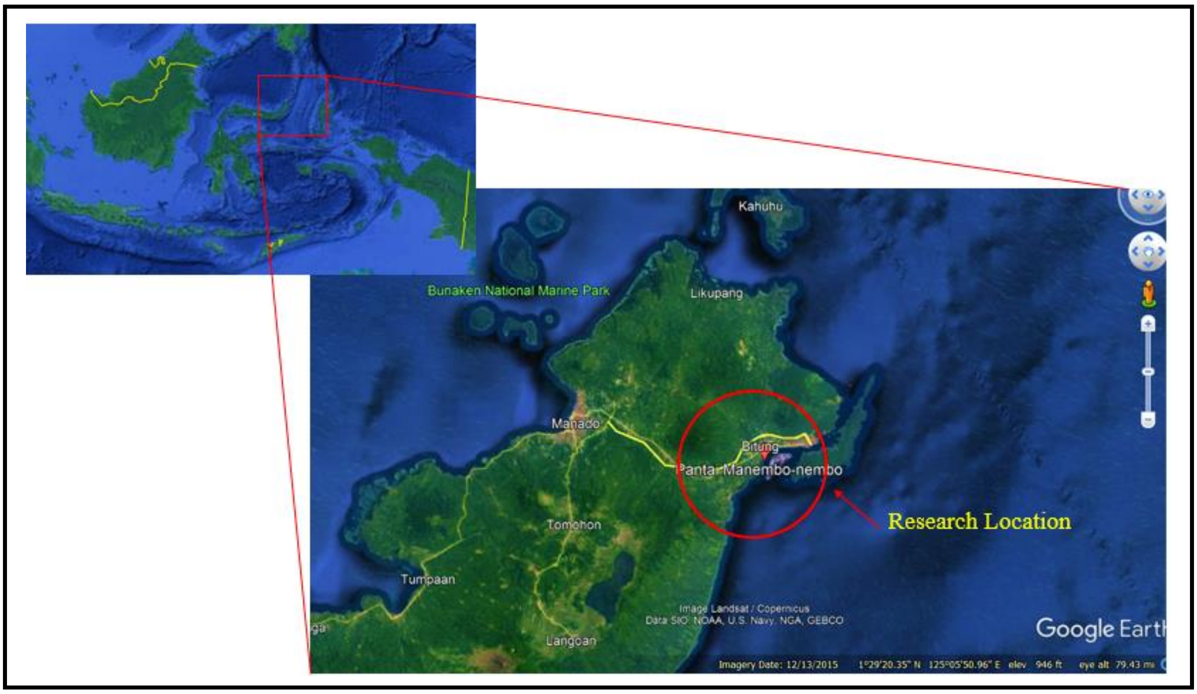

Fig. 1 Research Location

3. Research Methods

The relationship between tides and waves will occur abrasion and erosion; waves and ocean currents are factors causing the occurrence of abrasion and erosion on the coast. The presence of waves and currents of a destructive nature can cause the movement of the coastline. A change in the elevation of the water level, namely the tides coupled with waves, causes abrasion and erosion when the wave energy is large. (CERC,1984)The pressure caused by the wave is a combination of hydrostatic and hydrodynamic pressure. The magnitude of the pressure can be calculated by entering the given velocity potential in the equation that has been linearized.

$$\frac{\partial_\varphi}{\partial_t} + gy + \frac{p}{\rho} = 0 \quad (1)$$

$$p = -\rho gy - \rho \frac{\partial}{\partial_t} Sin(kx - \sigma t) \quad (2)$$

$$= -\rho gy + \left(\frac{\rho gH}{2}\right) \frac{cosh\ k(d+y)}{cosh\ kd} cos(kx - \sigma t) \quad (3)$$

The first part in the right segment in the equation above is the hydrostatic pressure, while the second is the hydrodynamic pressure caused by the acceleration of water particles.

This equation can calculate the pressure of a wave p, where:ρ is the specific gravity of seawater, g is gravity, y or h is the height of the water, H is the wave height, k=2π/L is the wave number, σ=2π/T is the wave frequency, x is the horizontal distance, L=wave length.

The research was conducted by collecting related data from literature studies, secondary and primary data, and analyzing secondary and primary data. Data analysis consists of primary data analysis and secondary data analysis. Secondary data in the form of wind data is calculated by wave hindcasting, where previously, it has been described as fetching wind drag areas to obtain related wave parameters such as wave height, period, and tidal data analysis by the Admiralty method to obtain the required water level elevation. Primary data is analyzed by directly identifying the coastal problem so that problems can be known at the location; therefore, the necessary actions can be taken. Comparing wave pressure from pressure due to wind waves and wave pressure due to tides. From this comparison, it can be concluded that it adds vertical wave pressure to the waters due to the presence of tides.

3.1. Fetch Effective Calculations

Fetch is effectively used in wave forecasting to determine waves' height, period, and duration.
The average effective fetch is :

$$F_{eff} = \frac{\Sigma X_i Cos\alpha}{\Sigma Cos\alpha} \quad (4)$$

This fetch effective length calculation is done using the help of topographic maps of locations with a considerable scale so that can be seen the islands or land that affect the generation of waves in a location.

Fetch (Xi) calculations from various possible directions are shown in (Fig. 2). below.

Determination of fetch points taken on the position of the deep sea from the location of the waters reviewed because waves generated by wind form in the deep sea of water, then propagate towards the coast and break while the waters are getting shallow near the coast.

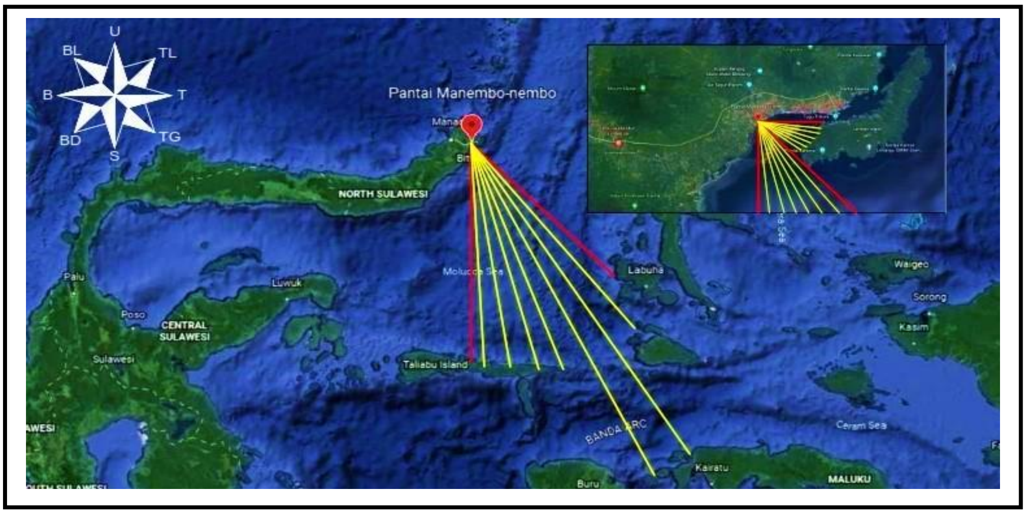

Fig. 2 Fetch of Manembo-nembo Girian Beach

The main wind direction is determined as the central line using a map of the Manembo-nemboGirian Beach coastal area. In calculations, the angle from the center line towards the right and left of the fetch line at an interval of 22.5°. Determination of fetch points taken on the position of the deep sea from the location of the waters reviewed because waves generated by wind form in the deep sea of water, then propagate towards the coast and break while the waters are getting shallow near the coast.

3.2. Wind Analysis

The wind data analyzed are data on the daily maximum wind speed and direction in the last 5 years, namely 2016-2021, which is the data obtained from the BMKG Maritim Bitung wind data source. The wind maximum to calculate significant wave height is first corrected to obtain the stress-wind factor value (wind-stress factor). Wind data is necessary for forecasts of wave heights and periods. Before changing wind speed into a wind stress factor, it must make corrections and conversions to wind speed data. To obtain the wind stress factor, such wind data must be corrected against elevation, stability, and location effects ($U_{.A.}$).The wind data used is the daily maximum wind data to be processed to obtain maximum wave height data. Calculate steps to get the U.A. value (for example, in the wind data for August 2021).

-Correction to elevationWind data are taken from the Bitung Maritime Meteorological Climatology and Geophysics Agency (BMKG) measured from an altitude of + 10 m from sea level

$$U(10) = U(y)\left(\frac{10}{y}\right)^{1/7} \tag{5}$$

If U(y)= 7.9 m/s and Z=10m then U(10)=7.9 m/s

- Correction of Stability and Location Effect

Since there is no data on the difference in the average temperature of air and seawater, $R_{.T.}$ = 1.1, while the $R_{.L.}$ value varies according to wind speed.

$$U_A=R_T.R_L.U_{10}$$

which U_A=wind stress factor (m/s), R_T= the correction factor of the temperature difference in sea and land, taken value 1.1, R_L=location correction factor (taken $R_{.L.}$ value in August 2021, for example), U_{10}= correction factor to elevation (taken U_{10} in August 2021). $U_A=R_T.R_L.U_{10}$=1.1x1.2x7.90=10.43m/s (Table 2.)

3.3. High and Periode of Wave Forecasting

The relationship of wave forecasting depending on the depth or forecasting of waves in shallow seas can be established as the following equation.

$$\frac{gH_{m0}}{U_A^2} = 0.283tanh\left[0.53\left(\frac{gh}{U_A^2}\right)^{3/4}\right]tanh\left[\frac{0.00565\left(\frac{gF}{U_A^2}\right)^{1/2}}{tanh\left[0.53\left(\frac{gh}{U_A^2}\right)^{3/4}\right]}\right] \tag{6}$$

$$\frac{gT_s}{U_A} = 7.54tanh\left[0.833\left(\frac{gh}{U_A^2}\right)^{3/8}\right]tanh\left[\frac{0.0379\left(\frac{gF}{U_A^2}\right)^{1/3}}{tanh\left[0.833\left(\frac{gh}{U_A^2}\right)^{3/8}\right]}\right] \tag{7}$$

$$\frac{gt_d}{U_A} = 537\left(\frac{gT_s}{U_A}\right)^{7/3} \tag{8}$$

For forecasting waves in the deep sea can be used formulas as next:

$$\frac{gH_{m0}}{U_A^2} = 0.0016\left(\frac{gF}{U_A^2}\right)^{1/2} \tag{9}$$

$$\frac{gT_p}{U_A} = 0.286\left(\frac{gF}{U_A^2}\right)^{1/3} \tag{10}$$

$$\frac{gt_d}{U_A} = 68.8\left(\frac{gF}{U_A^2}\right)^{2/3} \tag{11}$$

Given $U_A = 0.71U_{10}^{1.23}$ (12)

$$U_{10} = \left(\frac{10}{y}\right)^{1/7} \tag{13}$$

Where H_s =H_{m0} = significant wave height (m), U_A=wind speed factor (m/s), F= fetch length (m), T_s=0.95T_p= significant waves period (sec), td=duration or time length of the wind blows(sec), U_{10}=wind speed at an altitude of 10 meters (m/sec), Uz=wind speed measured at the height of z meters(m/s).

From the table of the results of this recapitulation(Table 4.), it can be known that the dominant and maximum waves originate from the South direction; waves from the South direction have a larger wave generation area than waves from other directions. Wave forecasting from daily wind data will also result in maximum extreme wave heights and periods. These extreme waves do not occur every day, so they cannot be considered a pattern representing coastal waves.

3.4. Tide

Tides are a phenomenon of the movement of the rise and fall of the seawater surface as periodic that result from a combination of gravitational forces of astronomical bodies, especially by the sun, earth, and moon. Tidal data taken from LANTAMAL VIII Manado from 7 to 21 December 2021is used to determine the type of tide and the elevation of sea level after being analyzed by the Admiralty method. The data obtained is depicted on the graph as in Fig.3. Tidal type can be determined based on Formzahl numbers, which expressed in the form of the equation

$$F = \frac{K_1 + O_1}{M_2 + S_2} \quad (14)$$

where F= Formzahl number, K_1=amplitude of tidal components K_1, O1= amplitude of tidal components O_1, M_2= amplitude of tidal components M_2, S_2= amplitude of tidal components S_2.The Formzahl number has a certain range for determining the tidal type of a region. With this Formzahl value, the tides are divided into 4 types, namely: semi-diurnal tide ($0< F\leq 0.25$), mixed-tide prevailing semi-diurnal ($0.25<F<1.25$),mixed-tide prevailing diurnal ($1.5<F\leq 3$),diurnal-tide ($F>3$).

The Admiralty method of harmonic analysis is a tidal analysis used to calculate 2 harmonic constants, namely amplitude A and phase difference g°. The calculation process of Admiralty method is calculated with the help of tables, where the time of observation which is not labeled, should be carried out through approach and interpolation. To facilitate the harmonic analysis of the Admiralty method, the development of calculations with the help of Excel is carried out. It will produce the parameters that are labeled. Such calculation stages use 8 groups of counts with the help of tables from the calculation of the Admiralty method.

The count using the Admiralty method, in summary, is as follows:

-Count group 1 on the count of this group is determined mid-observation, the highest and lowest readings. The highest reading indicates the highest tool position, and the lowest reading indicates the lowest.

-Count group 2,reading positive (+)and negative (-), were determined for columns X1, Y1, X2, Y2, X4, and Y4 on each day of observation.

-Count group 3,filling in columns X0, X1, Y1, X2, Y2, X4, and Y4 on each day of observation. Column X0 contains a horizontal calculation of the count X1 in the count group of 2 without regard to the signs (+) and (-). Columns X1, Y1, X2, Y2, X4, and Y4 are horizontal summations of X1, Y1, X2, Y2, X4, and Y4 in the count group 2 concerning the sign (+) and (-) must be added by the magnitude B(B multiples of 100).

-Count group 4, for the observation of 15 days, the amount that has been added B can be determined and then calculated X00, Y00 to X4d, Y4d where:

- index 00 for X means X00
- index 00 for Y means Y00
- index 4d for Y means Y4d
- index 4d for X means X4d

- Count group 5, calculations in this group have already paid attention to the nine main elements of tidal generation (M2, S2, K2, N2, K1, O1, P1, M4, and MS4).For the calculation of the count group 5 looking for the values of X00, X10, the difference between X12 and Y1b, the difference between X13 and Y1c, X20, the difference between X22 and Y2b, the difference between X23 and Y2c, the difference between X42 and Y4b and the difference between X44 and Y4d. For the calculation of the count group 6, looking for the value of Y10, the sum of Y12 and X1b, the sum of Y13 and X1c Y20, the sum of Y22 and X2b, the sum of Y23 and X2c, the sum of Y42 and X4d and the sum of Y44 and X4d.

-Count groups 7 and 8, determining the magnitude of P.R cos r, P.R sin r, determining the magnitude of p, magnitude f, determining the price of V', V'', V''' and V for each of the main elements of the tidal generation (M2, S2, K2, N2, K1, O1, P1, M4, and MS4), determining the price of u and price p and price of r.

Finally, this calculation will determine the price of w (1 +W), the amount of g, the multiple of $360^{0,}$ as well as the amplitude (A) and the phase difference (g^0).

4. Results and Discussions

Fig.3 tidal curve shows that the tide's highest water level position (HHWL) range is 2.10 m. The average high water (MHWL) is 1.836 m, the average water level position (MSL) is 1.20 m, the low water level position, the average (MLWL) is 0.56 m, and the lowest low water level position (LLWL) is 0.50m. Based on observational data, tidal analysis calculates the amplitude and difference of the phase nine tidal constant. This analysis used the Admiralty method. Tidal constant analysis results can be seen in Table 6.

Once the tidal component is known, the tidal type can be defined based on the Formzahl ratio formula. Using the formula, at the location obtained, the value of the Formzhahl F = 0.093. Since $0 < F \leq 0.25$, it means Manembo-nembo Beach has a semi-diurnal tide type where in one day, there are two tides, and also two receding with almost the same height, and the tides occur sequentially orderly.

Table 1. Wind Speed and Direction Data

2021				
No	**Month**	**Velocity**		**Direction**
		m/s	**knot**	
1	January	3.2	6.220288	E
2	February	3.1	6025904	E
3	March	2.8	5.442752	E
4	April	2.8	5.442752	E
5	May	4.9	9.524816	SW
6	June	5.8	11.2742	SW
7	July	5.7	11.079888	SW
8	August	7.9	15.356336	S
9	September	5.8	11.274272	SW
10	October	6.9	13.412496	SW
11	November	5.6	10.885504	SW
12	December	6.2	12.051808	W

Sources: BMKG

Table 2. Wind Stress Factor Calculation in 2021

Wind Stress Calculation Factor 2021					Z=±	1.0
					RT	1.1
Month	Direction	Uz	Uz rounded	$U_{10} = \mathrm{Uz}\left(\frac{10}{\mathrm{Z}}\right)^{\frac{1}{7}}$	R.L.	UA=RT.RL.U10
January	E	3.200	3.2	3.20	1.59	5.60
February	E	3.100	3.1	3.10	1.61	5.49
March	E	2.800	2.8	2.80	1.63	5.02
April	E	2.800	2.8	2.80	1.63	5.02
May	SW	4.900	4.9	4.90	1.42	7.65
June	SW	5.800	5.8	5.80	2	12.76
July	SW	5.700	5.7	5.70	1.37	8.59
August	S	7.900	7.9	7.90	1.2	10.43
September	SW	5.800	5.8	5.80	1.36	8.68
October	SW	6.900	6.9	6.90	1.29	9.79
November	SW	5.600	5.6	5.60	1.38	8.50
December	W	6.200	6.2	6.20	1.32	9.00

Sources: Calculation Result

Table 3. Hindcasting Calculation of Maximum Wave in 2021

ti	21600												
g	9.81												
Month	Direct	Feff	ti	t_{fetch}	Wave Cond	H_0	T_0	$\frac{gH}{U^2{}_A}$	$\frac{gT}{U_A}$	$\frac{gt_i}{U_A}$	Fully/ Non Fully	H_0	T_0
		km	s	s		m	s					m	s
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Jan	E	5.28	21600	5491.71	FL	0.212	1.953	0.066	3.423	37860.21	NF	0.212	1.953
Febr	E	5.28	21600	5527.06	FL	0.209	1.945	0.068	3.475	38596.02	NF	0.209	1.945
March	E	5.28	21600	5694.31	FL	0.194	1.906	0.075	3.725	42207.00	NF	0.194	1.906
April	E	5.28	21600	5694.31	FL	0.194	1.906	0.075	3.725	42207.00	NF	0.194	1.906
May	SW	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	27685.07	NF	0.00	0.00
June	SW	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	16606.27	NF	0.00	0.00
July	SW	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	24668.04	NF	0.00	0.00
August	S	357.92	21600	74157.7	DL	1.127	4.513	0.102	4.245	20319.91	NF	1.127	4.513
Sept	SW	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	24420.98	NF	0.00	0.00
Oct	SW	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	21641.70	NF	0.00	0.00
Nov	SW	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	24926.60	NF	0.00	0.00
Dec	W	0.00	21600	0.00	FL	0.00	0.00	0.00	0.00	23537.72	NF	0.00	0.00

Sources: Calculation Result (Note: FL=fetch limited, DL=duration limited, NF=non fully developed)

Table 4. Recapitulation of the direction, height, and wave period of each fetch based on Wave Hindcasting in 2016 – 2021

Month	H-T	The direction of coming waves			Maximum every month	
		E	S-E	S	H-T	Direction
January	H	0.212	0	0.723	0.723	S
	T	1.953	0	3.683	3.683	
February	H	0.267	0.000	0	0.267	E
	T	2.077	0.000	0	2.077	
March	H	0.303	0.000	1.054	1.054	S
	T	2.148	0.000	4.377	4.377	
April	H	0.247	0	1.072	1.072	S
	T	2.034	0	4.411	4.411	
May	H	0.000	0	0.271	0.271	S
	T	0.000	0	2.349	2.349	
June	H	0.000	0	1.000	1.000	S
	T	0.000	0	4.273	4.273	
July	H	0.000	0.000	1.127	1.127	S
	T	0.000	0.000	4.513	4.513	
August	H	0.000	0	1.127	1.127	S
	T	0.000	0	4.513	4.513	
Sept	H	0.000	0	1.036	1.036	S
	T	0.000	0	4.342	4.342	
Oct	H	0.000	0	0.518	0.518	S
	T	0.000	0	3.161	3.161	
Nov	H	0.000	0.302	0.250	0.302	SE
	T	0.000	2.467	2.266	2.467	
Dec	H	0.122	.000	0.000	0.122	E
	T	1.685	.000	0.000	1.685	
Maximum every direction					1.127	S
					4.513	

Sources: Calculation Result

Table 5. The result of Seawater Elevation

Symbol	Unit	Elevation
HHWL	Cm	210
MHWL	Cm	183.60
MSL	Cm	120
MLWL	Cm	56.94
LLWL	Cm	50

Table 6. Tidal Component Harmonic

	S0	M2	S2	N2	K1	O1	M4	MS4	K2	P1
A(cm)	120	51	25	4	19	10	1	19	7	6
g^0	0.00	106.62	203.44	238.59	350.50	64.90	111.96	286.13	203.44	350.50

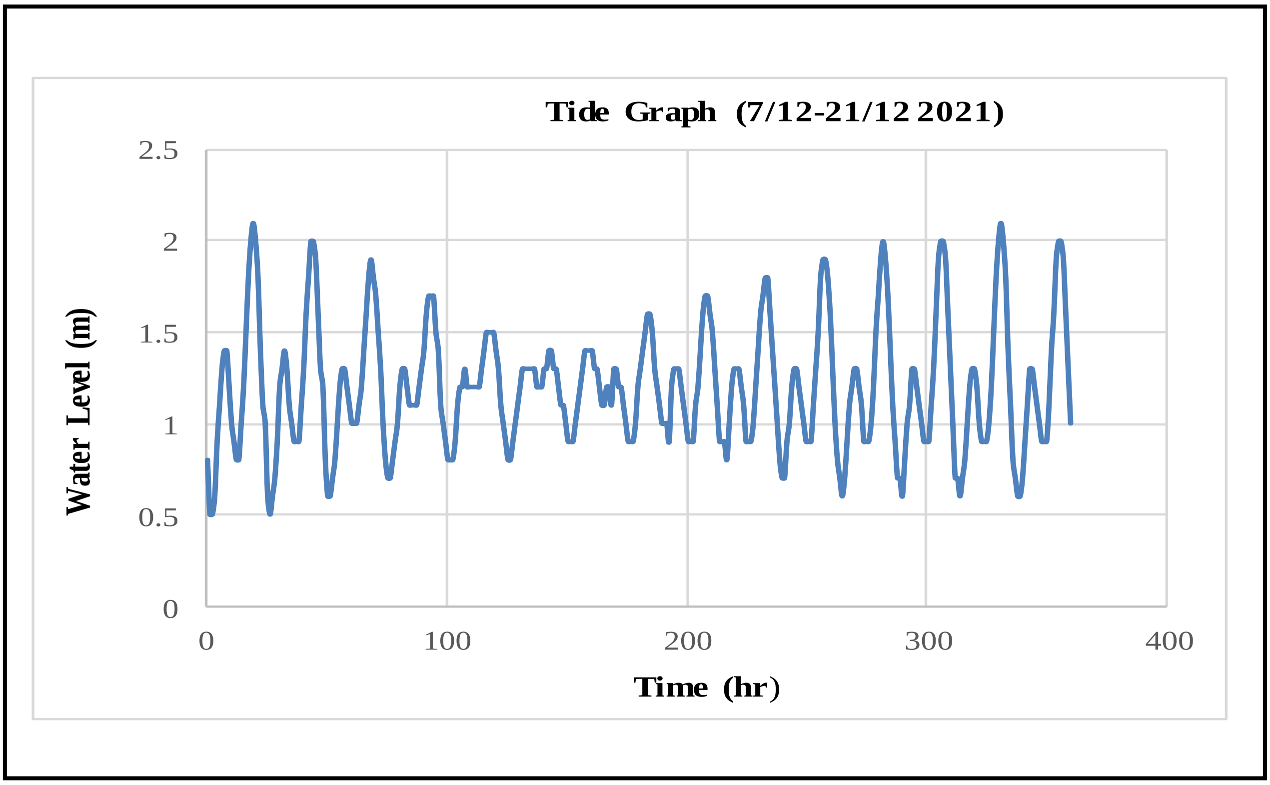

Fig. 3 Graph of Tide on 7/12-21/12, 2021

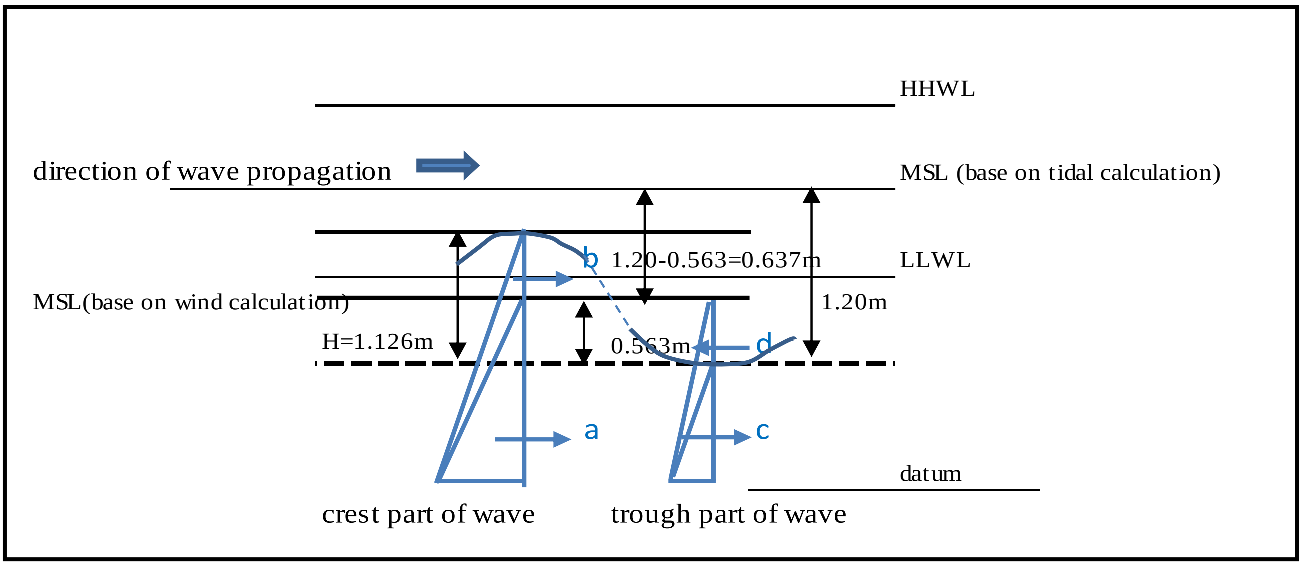

Fig. 4 Vertical pressure distribution of wave on crest and trough due to wind wave

In Table 3. and Table 4. the calculation of wave hindcasting obtained wave height H = 1,126m with a period of T = 4,512 sec. Effective fetch calculations for the main direction are about 200km.

The pressure of wave (p) as in equation (3):

The pressure caused by the wave (hydrodynamic pressure) gradually decreases from the water level to the bottom of the water. It is influenced by the value of cosh k(d+y)/coshkd, where it is based become –y so that cosh k(d+y) =1 equation (3). The value of cosh k(d+y)/coshkd becomes 1/coshkd which becomes very small or zero by the time the kd becomes very large. In the distribution of wave pressure on the virtual wall, the wave pressure due to the wind is magnified by the water level rising due to tides. It indicates that the tides affect the vertical pressure distribution due to the wave. Fig. 4 illustrates the tidal elevations compared to the wind-induced wave elevations, namely amplitude and wave heights with a certain datum. The existing pressure distribution describes the vertical pressure distribution of the wave due to wind. The notation a is the hydrostatic pressure on the wave crest part, the b notation is the hydrodynamic pressure on the wave crest part, and notation c is the hydrostatic pressure on the trough part of the wave, the notation d is the hydrodynamic pressure on the trough part of the wave.

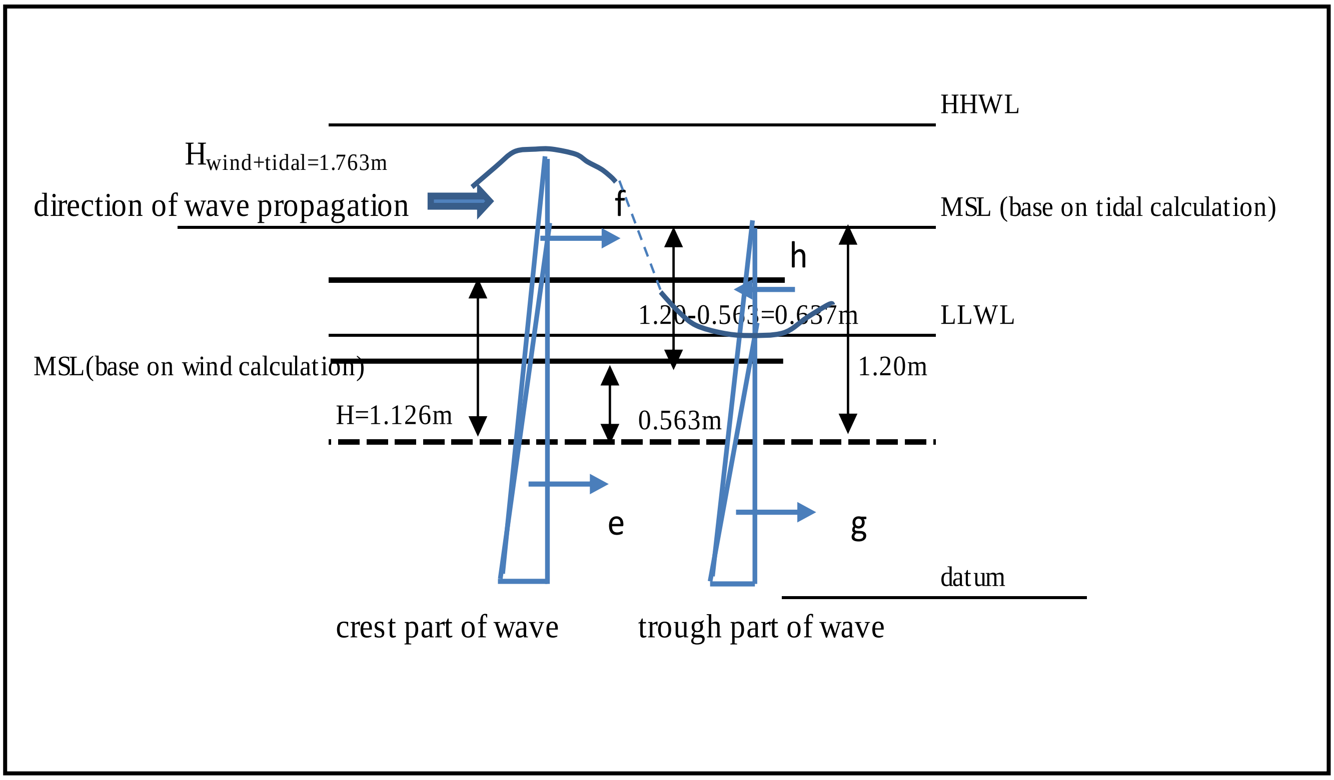

Fig. 5 Vertical pressure distribution of wave on crest and trough due to wind combination tidal

Fig. 5 describes the vertical pressure distribution of waves due to wind and tidal. The notation e is the hydrostatic pressure due to wind and tides, and the notation f is the hydrodynamic pressure on the crest part of the wave. The notation g is the hydraulic pressure in the trough part of the wave, while the notation h is the hydrodynamic pressure in the trough part.

For example case, if ρ= specific gravity of sea water=1030 kg/m^3, H=wave height=1.127m, g=gravitational acceleration=9.8m/s^2, L=wave length=30.727m, k=wave number=2π/L=0.204,and if d=-y. Fig.4 for wind wave, the pressure of wave in crest =11.662t(force resultant is the same direction of wave propagation), in trough =2.607t (opposite direction), Fig.5 for wind and tidal, wave pressure in crest=45.34t(same direction with wave propagation), in trough wave pressure=2.918t(same direction).

5. Conclusion

Analysis conducted on the wind wave and wind combination tidal on the coast of Manembo-nemboGirianBitung using wind data during 5 years (2016-2021) and tidal data from 7/12 to 21/12 2021, getting wave height H=1.127m, wavelength L=31.727m, and tidal result MSL=120cm. Based on the case of a comparison between wind wave and wind combination tidal, the wave pressure was obtained at 11.662 t in the crest and 2.607t in the trough of wave affected by wind, and 45.34t in the crest and 2.918t in the trough of wave combination tidal. It indicates that the tide can enlarge the vertical pressure distribution of waves.

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