The Use of Piezoelectric as Energy Harvester in Breakwater

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Abstract. Nowadays, in the case of the coastal structures, wave breaking and access to clean energy are two important issues, which can be addressed by combining breakwater and vibration-based energy harvesting systems. In the study, the mechanical energy harvester which is produced from the transvers wave motion of water particles is developed by the piezoelectric motion in the breakwater and resulting electrical energy. To study the application of this system, a theoretical model is presented. This study has the objective to know the wind analysis, wave estimation and potential of power produced by sea waves on Enggano Bengkulu island is an area with large potential of sea wave energy. From the result of the research is the wave height 1.035 m and wavelength 44.902 m is also strongly suggest to produce energy for 7.51 kW into breakwater. The results of this project demonstrated that wind analysis, wave estimation with Weibull method and the design of breakwater with piezoelectric system can be utilized to absorb wave energy. This research develops breakwater construction with piezoelectricity as a result, potential novel renewable energy by offshore infrastructure.

1. Introduction
Sea waves are the movement of the rise and fall of sea water perpendicular to the sea surface which forms a sinusoidal curve/graph (Holthuijsen 2007). In the development of the search for alternative energy, ocean waves had become one of the most abundant energy sources. The absence of utilization causes open wave to become a waste of energy.

Over the decade energy has been the basic human needs for survival. Energy is a form of force generated by object (Pardiyono). Energy harvesting from wasted energy to run low powered electronic has emerged over the last few decades. The purpose of this technology is to provide a remote power source (Erturk & Inman 2011).

Piezoelectric energy harvesting (Erturk & Inman 2011) is one of the most important method of harvesting the wasted energy from ocean wave. Piezoelectric material can be used to convert mechanical oscillation energy into electrical energy (Christopher A Howell 2009). Harvesting of mechanical
oscillation energy from the sea water waves through piezoelectric can be done by utilizing a breakwater. Piezoelectric placement on the breakwater is done by tethering one end of the piezoelectric, so that it will form a cantilever. This placement can have the advantage of increasing output power by using less material (Buriani & Renzy 2017). This research has analysis the wind, wave estimation and potential of power produced by sea waves on Enggano Bengkulu island by developed breakwater construction with piezoelectricity for potential novel renewable energy by offshore infrastructure.

2. Method
2.1 Description of Research Site
This research was conducted in the area of Enggano island. The island has some potential that can improve the economy in the area. (Akbar & Yati 2018), one of them is the ocean waves. Enggano Island is geographically located in the ocean region of Indonesia. Astronomically this island is located at coordinates 05° 23′ 21" S, 102° 24′ 40" E. Enggano Island is also included in the area of North Bengkulu Regency, Bengkulu Province. The total area of Enggano island ranges from 400.6 km². Around Enggano island there are also other small islands namely Pulau Dua, Merbau and Pulau Satu. The average daily temperature ranges between 27.8 °C and a high of 34 °C. Nisbi humidity is generally above 80% with lows at 78% and highs at 96%. This indicates that on Enggano island the humidity of the air is relatively high throughout the year. The dominant winds are divided into two seasons, namely the west monsoon (occurring from September to January) and the southeast monsoon (April).

![Figure 1. Kahpayu Port, Enggano Island, Bengkulu](image)

The potential of the waters on the island of Enggano, namely in the form of sea waves that can be utilized as an energy resource, especially for the surrounding community. Based on BMKG data, Enggano island has a significant sea wave height. In the image below, it can be seen clearly that the waters on Enggano island show a significant wave height as illustrated in Figure 2. Kahpayu port is located on the south coastal line of Enggano Island, Indonesia. Kahpayu port is one of important ferry ports for goods shipment from Sumatera in Enggano Island. Currently, this port lack of shore protection as illustrated in Figure 1.
2.2 Breakwater

In this study, the breakwater was used as a place where piezoelectric was placed. Breakwater building is a construction that can be built parallel or perpendicular to the coastline that serves to protect the waters behind it against wave attacks (Dzakia & Bambang 2017). The selection of the type of breakwater needs to be adjusted to the needs of piezoelectric placement, which in this case selected the breakwater with the type of vertical instead of revetment. More specifically the selected breakwater is a caisson breakwater because the observed location is offshore and it is not possible to use sheet pile type. Breakwater structures material is consist of reinforced concrete (2,400 kg/m3) and cyclopean concrete (2,200 kg/m3). As importance of this port for Enggano Island economy and in order to guarantee the
protection of port, deep water breakwater will be constructed to surround harbour zone. The planned structure form is caisson breakwater as shown in Figure 3. Section and dimensions of the Proposed Caisson Breakwater.

2.3 Piezoelectric

The selection of energy harvesters in this study is piezoelectric. Piezoelectric is considered very suitable to be applied in this study because it fits perfectly with the design of the breakwater. In this case, the selected piezoelectric with cantilever structures which mounted by being linked to the breakwater. Cantilevers are usually bimorph structures comprising two piezoelectric materials bound together, with a shim in between them to maximize the energy extraction yield. Piezoelectric used in this study has dimensions with a length of 3 meters, a width of 1 meter, and a total thickness of 0.1 meters. The type of material used is PZT (Lead Zirconate Titanate). The piezoelectric shown in Figure 3.

![Figure 3. Proposed Caisson Breakwater](image)

2.4 Method

The analysis methods used for this research analysis are:
1. Analysis of wind data obtained from BMKG station class 1 Bengkulu through SMB method
2. Analysis of wave estimates generated from wind data by SMB method
3. Analyse the energy potential of seawater waves based on data from wave forecast analysis.

The following results are the results of the analysis of the data that we have obtained then processed with related formulas and assisted with data processing software.

In data analysis, the following data are used
- Wind Data
  The caisson breakwater designed based on wind data from the nearest climatology station from Kahyapu Port, Stasiun Klimatologi Kelas I Bengkulu. Wind data include maximum wind speed, wind direction, and observation station elevation. The wind data period is three-years wind data from 2017 to 2019. This data is used for wave analysis.
- Fetch
  Fetch is the distance waves across open water where in this design estimated using software AUTOCAD. Fetch effective calculated based on fetch analysis according to the following formulations by CERC, 1984:

\[
Feff = \frac{\Sigma x \cos \alpha}{\Sigma \cos \alpha}
\]
- Topography
  Topographic data used to extract slope data in the location. This data is used for breaking wave calculation.

2.5 Wave Forecasting
Wave forecasting in this analysis is illustrated in Figure 5

![Flow chart and wave forecasting formula (CERC, 1984)](image)

**Figure 5.** Flow chart and wave forecasting formula (CERC, 1984)

2.6 Data Analysis
In order to investigate wave height and period for designing caisson breakwater, first wind data were analysed and output of analysis is wind rose as illustrated in table 1.

| Wind Speed | N     | NE    | E     | SE    | S     | SW    | W     | NW    | Total  |
|------------|-------|-------|-------|-------|-------|-------|-------|-------|--------|
| 0-10       | 0.00% | 1.55% | 1.10% | 8.31% | 31.51%| 12.69%| 41.00%| 3.84% | 100.00%|
| 11-13      | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00%  |
| 14-16      | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00%  |
| 17-21      | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00%  |
| 22-27      | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00%  |
| >27        | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00%  |
| **Total**  | 0.00% | 1.55% | 1.10% | 8.31% | 31.51%| 12.69%| 41.00%| 3.84% | 100.00%|

According to wind analyses, dominant wind directions are from west, south, and south west.
Next, analysis using fetch data to get effective fetch as presented in Table 2. South fetch was chosen in this analysis because of where port is located and representation of waves in southern Enggano Island.

### Table 2. Fetch of the South

| No | α   | cos(α) | Xi  | Xi. cos(α) |
|----|-----|--------|-----|------------|
| 1  | -42 | 0.743  | 13943 | 10361.973 |
| 2  | -36 | 0.809  | 12314 | 9962.237  |
| 3  | -30 | 0.866  | 10642 | 9216.655  |
| 4  | -24 | 0.914  | 10598 | 9681.356  |
| 5  | -18 | 0.951  | 105145| 99998.390 |
| 6  | -12 | 0.978  | 9622  | 9411.931  |
| 7  | -6  | 0.995  | 9399  | 9347.617  |
| 8  | 0   | 1.000  | 9133.338| 9133.338 |
| 9  | 6   | 0.995  | 9323.107| 9272.034 |
| 10 | 12  | 0.978  | 9678.954| 9467.446 |
| 11 | 18  | 0.951  | 9669.845| 9196.569 |
| 12 | 24  | 0.914  | 3646.702| 3331.428 |
| 13 | 30  | 0.866  | 2475.614| 2143.945 |
| 14 | 36  | 0.809  | 2336  | 1889.645 |
| 15 | 42  | 0.743  | 2359  | 1752.729 |
|    |     | **Total** | 13.51 | 220285.10 | 204167.29 |

| Fetch eff | 15111.283 |

To predict significant wave the author use Sverdruv Munk Bretschneider (SMB) methods. According to analysis result, significant wave height (H33) is 0.514 m and period is 9.446 s. Significant wave height and period is input to re current period. Analysis result shows in Table 3 and Table 4.

### Table 3. Comparison of Wave Height with Various Methods

| Re current Period | Fisher-Tippet Type 1 | Weibull |
|-------------------|----------------------|---------|
|                   | K=0.75 | K=1    | K=1.4  | K=2     |
| 2                 | 0.540  | 1.323  | 1.37   | 1.42    | 1.470153 |
| 5                 | 0.921  | 1.250  | 1.26   | 1.27    | 1.272892 |
| 10                | 1.172  | 1.183  | 1.18   | 1.17    | 1.160352 |
| 25                | 1.491  | 1.084  | 1.07   | 1.05    | 1.03519  |
| 50                | 1.727  | 1.003  | 0.98   | 0.97    | 0.952066 |
| 100               | 1.961  | 0.916  | 0.90   | 0.89    | 0.876034 |
Table 4. Comparison of Wave Period with Various Methods

| Re current Period | Fisher-Tippet Type 1 | K=0.75 | K=1 | K=1.4 | K=2 |
|-------------------|----------------------|--------|------|--------|------|
| 2                 | 1.257                | 6.004  | 6.11 | 6.23   | 6.34 |
| 5                 | 3.922                | 5.843  | 5.87 | 5.89   | 5.90 |
| 10                | 5.687                | 5.697  | 5.68 | 5.66   | 5.65 |
| 25                | 7.916                | 5.480  | 5.44 | 5.40   | 5.37 |
| 50                | 9.569                | 5.302  | 5.25 | 5.21   | 5.18 |
| 100               | 11.211               | 5.113  | 5.07 | 5.03   | 5.01 |

This analysis use Weibull (K = 2) as re current period periodic significant wave method where H = 1.035 m and T = 5.365 seconds.

2.7 Breaking Waves

Breaking waves is critical for breakwater construction. In this design, author analyse breaking waves height and depth. Depth of breaking waves estimated by using following formula by Triatmodjo, 2014:

\[ Db = \frac{H_b}{b^{a + \frac{H_b}{g T^2}}} \]

According to analysis breaking waves height is 0.9 m and its depth is 1.027 m.

2.8 Caisson Breakwater

Breakwater was designed based on estimation of waves height and period. From stability analysis, sliding safety factor is 4.226 and over turning safety factor is 11.44. In this stability control authors were not considering earthquake and geotechnical properties in location. Breakwater is a caisson structure that consist of cyclopean concrete, concrete, core, and rubble armour layer for toe protection.
2.9 Construction Cost

Caisson Breakwater construction estimation cost per 100 m illustrated in Table 5

Table 5. Estimated Construction Cost

| Material                  | Volume per meter | Unit | Volume of Works | Unit | Unit Price | Estimated Cost       |
|---------------------------|------------------|------|-----------------|------|------------|----------------------|
| Cyclopean Concrete        | 20.625           | m2-m | 2062.5          | m3   | Rp2,650,439| Rp5,466,530,438      |
| Rubble Armour             | 12.497           | m2-m | 1249.7774       | m3   | Rp280,000  | Rp349,937,661        |
| Embankment Concrete +     | 31.404           | m2-m | 3140.4512       | m3   | Rp130,000  | Rp408,258,657        |
| Reinforcement Precast     | 31.25            | m2-m | 3125            | m3   | Rp6,383,804| Rp19,949,388,781     |
| Precast Concrete          | 0.44             | m2-m | 44              | m3   | Rp6,383,804| Rp280,887,394        |

2.10 Wave Energy Analysis

Despite its function as shore protection, the breakwater can be used to harvest wave energy by attaching piezoelectric in open sea side of breakwater. The wave power based on 25 years re current period period wave theoretically is up to 7.51 kW each meter of breakwater.

2.11 Potential Energy Calculation

Potential energy generated by ocean waves is obtained through calculation by utilizing the results of wave forecast analysis with the SMB method. The following are the potential energy generated in the 25 years re current period wave:

From the wave forecast data, be aware of:
- Density of Sea water ($\rho$) = 1,025 kg/m³
- Wavelength (H) = 1.035 m
- Wavelength at 25 years re current period (L) = 44.902 m
- Gravity (g) = 9.81 m/s²

Thus the amount of potential energy generated by ocean waves in the use of piezoelectric as an energy harvester is as following theoretic formulations by Triatmodjo, 2014:

$$\text{Potential Energy} = \frac{\rho gh^2L}{16}$$

$$= \frac{1025 \times 9.81 \times 1.035^2 \times 44.902}{16}$$

$$= 30228.69 \text{ Joule} = 30.228 \text{ Kilo Joule}$$

2.12 Kinetic Energy Calculation

The kinetic energy generated by ocean waves is obtained through calculations by utilizing the results of wave forecast analysis with the SMB method. The following is the amount of kinetic energy produced in the 25 years re current period of the wave:
From the wave forecast data, be aware of:

- Seawater Density ($\rho$) = 1,025 kg/m$^3$
- Wave Height at 25th re current period (H) = 1.035 m
- Wavelength at 25th re current period (L) = 44.902 m
- Period (T) = 5.37 second
- Earth gravity (g) = 9.81 m/s$^2$

Thus the amount of kinetic energy produced by ocean waves in the use of piezoelectric as an energy harvester is as following theoretic formulations by Triatmodjo, 2014:

$$\text{Kinetic Energy} = \frac{\rho g H^2 L}{16}$$

$$= \frac{1,025 \times 9.81 \times 1.035^2 \times 44.902}{16}$$

$$= 30,228.69 \text{ Joule}$$

$$= 30.228 \text{ Kilo Joule}$$

### 2.13 Total Energy Calculation

After the calculation of potential energy and kinetic energy, then summed up to get a large estimate of the energy generated from ocean waves. Here is a mathematical calculation to get the Total Energy generated by ocean waves.

From the wave forecast data, be aware of:

- Seawater Density ($\rho$) = 1,025 kg/m$^3$
- Wave Height at 25 years re current period (H) = 1.035 m
- Wavelength at 25 years re current period (L) = 44.902 m
- Earth gravity (g) = 9.81 m/s$^2$

Thus the total amount of energy generated by ocean waves in the use of piezoelectric as an energy harvester is as following theoretic formulations by Triatmodjo, 2014:

$$\text{Total Energy} = \frac{\rho g H^2 L}{8}$$

$$= \frac{1,025 \times 9.81 \times 1.035^2 \times 44.902}{8}$$

$$= 60,457.38 \text{ Joule}$$

$$= 60.457 \text{ Kilo Joule}$$

### 2.14 Calculation of Potential Power

The calculation of power is carried out after obtaining the total amount of energy generated by ocean waves. Here is the calculation of the power generated by ocean waves as following theoretic formulations by Triatmodjo, 2014:

$$P = \frac{nE}{T}$$

From the wave forecast data, it is known:

- Mean sea level and sea bed distance (d) = 10.161 meter
- Wave period (T) = 5.365 seconds
- Wave number $2\pi/L$ (k):

$$k = \frac{2\pi}{L} = \frac{2\pi}{44.902} = 0.139931079 \text{ radian/m}$$
\[ 2kd = 2 \times 0.139931 \times 10.161 = 2.843679 \text{ radian} \]

Summarize of wave:

\[ n = \frac{1}{2} \left( 1 + \frac{2kd}{\sinh 2kd} \right) \]
\[ = \frac{1}{2} \left( 1 + \frac{2.843679386}{2.8856032291} \right) = 0.666097 \]

Potential Power \((P) = \frac{nE_{\text{Total}}}{T} \]
\[ = \frac{(0.666097)(60.457)}{5.365} = 7.51 \text{ Kilo Watt} \]

From a series of calculations, 7.51 Kilo Watt of potential power was obtained from waves in Enggano island area with an altitude of 1.035 meters and a wavelength of 44.902 meter.

### 2.15 Piezoelectric Specifications

| Material       | PZT82          |
|----------------|----------------|
| Dimensions     | 1 x 0.26 x 0.00011 m |
| Electromechanical Coupling Coefficient | > 0.52 |
| Dielectric Loss | < 0.3% |
| Static Capacitance | 17950 pF ± 12% |
| Structural Steel | 0.01 m |

### 2.16 Piezoelectric Circuit System Design

In planning a piezoelectric circuit system, the energy source generated by the piezoelectric will be stored in a battery (energy storage). The energy source generated by the piezoelectric is an AC (Alternating Current) so it needs to be connected to an electronic circuit, namely a full bridge rectifier circuit that can convert AC (Alternating Current) electricity to DC (Direct Current). After the electric current changes to DC (Direct Current), the result of the output DC (Direct Current) voltage produced by the full rectifier has a value lower than the input voltage. Therefore, over long distances, the output voltage is not high enough to power electronic circuits, so a buck boost converter (Figure 8 a) is needed which functions steps up voltage (while stepping down current) from its input (supply) to its output (load). Buck boost converter is operated in a continuous mode so that the end-to-end circuit of the inductor is never zero, so the way buck boost converter works will only be affected by the duty cycle (D) Then the electricity can be stored in the batteries. The stored electrical energy is then distributed through a voltage regulator as it can be used, for example, as lighting for roads and ports on the island of Enggano.
3. Result and Discussion

From a series of calculations, 7.51 kilo Watts of potential power was obtained from waves on the Enggano island area with 25 years recurrent period waves height of 1.035 meters and a wavelength of 44.902 meters. Calculated to produce energy with analysis breaking waves height is 0.9 m and its depth is 1.027 m. Which we have obtained through analysis of wind data, analysis of wave estimates generated from wind data obtained from BMKG station class 1 Bengkulu through SMB method and analyse the energy potential of seawater waves based on data from wave forecast analysis so that known wind data, fetch and topography with wave characteristics in such a way required breakwater construction according to construction standards in order to withstand waves of this size. The results of previous research explain the potential of piezoelectric. This research focuses on the energy potential that can be generated from any movement of seawater waves.

Piezoelectric used to explain one application in energy harvesting. The authors calculated the use of piezoelectric based on theoretical calculations. According to (Triwahyuni, 2010) piezoelectric is a reversible effect where there is a direct piezoelectric effect the production of potential electricity due to mechanical pressure and piezoelectric effect of reverse pressure production due to the administration of electrical voltage resulting in dimensional changes. The piezoelectric material can experience deflection by being directly pressured or misery through intermediate media such as cantilever. Direct pressure administration will produce piezoelectric voltage comparable to the large press force. The benefit of piezoelectric materials can produce a potential difference large enough that it is widely used as a source of high voltage. Piezoelectric has begun to be used in Japan, precisely at the East Japan Railway Company (JR East) electric railway station as an alternative to the energy ticketing system, departure display, and lighting. The application of piezoelectric is for example if one-foot pressure step that can turn on the lamp with 60 Watts of power for one second, then with a little calculation management JR East Station is confident that with an effective floor trampled by 25 m² it will produce a power of 1400 kW. This energy can run one electric train (Saputri, 2011)

This research scope is limited to theoretical calculations and for validation results it is recommended to compare experimental methods and software simulations.

4. Conclusion

From a series of analysis 7.51 kilo Watts of potential power was obtained from waves on Enggano island area with the wave height of 1.035 meters and a wavelength of 44.902 meters. Through analysis of wind data obtained from BMKG station class 1 Bengkulu, wave forecasts generated from wind data with SMB method and analysis of seawater wave energy potential based on data from wave forecast analysis so that we can analyse breaking waves and breakwater structures that can survive according to the characteristics of the waters that we have calculated. In addition, we can also find out the estimated cost of building breakwater according to the wave. By this research, it can be concluded that ocean wave
energy has the potential to be developed into renewable energy. By reviewing the regions that have the characteristics of large waves as well as remote areas in Indonesia that do notably difficult to access electricity, becomes to advantages for the development of renewable energy.

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