Determination of the length of Bogowonto double jetty as the river mouth stabilization

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Abstract. One of the problems around estuaries with the wave-dominated combination of a small tidal range and low river discharges in the dry season was the mouth closed by a sand barrier. Longshore sediment flows silted up the river mouth while river flows were insufficiently large for flushing sand barriers. When the wet season started, river discharge suddenly enlarged. Discharge can't flow through the river mouth due to being hindered by the sand barrier. The consequence was that the hinterlands were inundated. Yogyakarta International Airport (YIA) is located in a coastal area of Kulon Progo regency, between two river mouths (Bogowonto river and Serang River). The two rivers have unstable river mouths. The double Jetty had been built at the Bogowonto river, but its condition was damaged. Meanwhile, the breakwater was constructed at the river mouth Serang and called Tanjung Adikarto. Double Jetties will be built to stabilize the Bogowonto river mouth. The purpose of this paper is to provide an overview of the length of the Jetty to be more effective in stabilizing the Bogowonto river mouth. Therefore, so that more easily opened by river flow and does not cause excessive erosion on the one side of the Jetty.

Keywords: double Jetty, estuaries, river mouth stabilization

1. Introduction
A jetty is constructed on each side of the river mouth to stabilize it [1]–[7]. Generally, the shifting of the river mouth cause problems, especially when areas on both sides of the river has been utilized. Yogyakarta International Airport (YIA) is a vital object located in Yogyakarta's south coastal area along the coast of the Serang River Estuary (Glagah Beach) to the Bogowonto River Estuary (Congot Beach) which has a distance of 2 km, shown in Figure 1. This zone has a sandy littoral zone and is characterized by dunes, beach ridges, and swales. Along the area, the coast is wave-dominated. The wave field is dominated by swell waves, relatively low and long waves, generated by westerlies in the Southern storm wave belt. These high-energy waves are uniform in direction, shape, and size, with a typical significant
wave height of 1.5 m with wave periods of about 10 s. Seasonal variations are small compared to storm waves.

The characteristic of the river mouth on the south coast of Yogyakarta is that it tends to turn, and the mouth of the mouth is closed by a sand barrier. The existence of a sand barrier that is blocking the river mouth is one of the characteristics of wave-dominated estuaries [8][9][10]. River discharge is very low in the dry season, coupled with small tidal range conditions (neap tide). It often resulted in river flows that were insufficiently large for flushing sand deposits in the sea. Additionally, under prevailing wave conditions and longshore sediment transport that large enough, a spit usually developed that blocked the creek of the river.

Figure 1. Yogyakarta International Airport (YIA) Location

When the wet season started, the river flow suddenly gained high discharges that approached the sand barrier. The hinterlands are inundated, while the area around the river mouth experiences flooding, endangering the airport. Flooding can be prevented if villagers dig the sand-plug (for the opening of the channel) when the discharge is expected to be high. When the timing was right, the river could penetrate the sand spit and expand naturally by dissolving the surrounding sediment. However, when the villagers dug too early, the system was naturally covered by longshore sediment transport quickly. Furthermore, when the river discharge becomes large, Bogowonto River overflows, and the area around the river mouth is most prone to floods.

Figure 2. Jetties at the Bogowonto river mouth
Jetties in the Bogowonto river have already been built since Dutch colonialism. However, the condition is already damaged and difficult to repair, shown in Figure 2. The height of the top of jetties is not high enough (+3.0 m only), where the minimum height of the jetties should be +4 m. Due to the passing of wave run-up or wave up-rush over the jetties’ heads, sand enters the river mouth. From the field observations, closing a river mouth can raise the water level upstream about 0.5 to 1.0 m. These data appear consistent with the probable elevation of the plug (according to the tide and waves characteristics). Based on these conditions, the jetties of Bogowonto need to be repaired. With the construction of a double jetty at the mouth of the Bogowonto river, it expected can no longer shift either to the west or to the east. The location of the river mouth is stable, and it remains between the double Jetty. The determination of Bogowonto's jetty length is one of the problems that need to be resolved. The length of the jetties will affect longshore sediment transport on the western side and eastern sides of the Jetty.

As stated previously, YIA is located at the eastern side of Bogowonto's river mouth. In contrast, the western side has been developed into a mangrove tourism area. For fishing port purposes and protection against river floods in the estuary, breakwater had built at the river mouth Serang and called Tanjung Adikarto. They should also minimize the sediment movement coming from the longshore direction. The navigation channel can still be passed by the fishing boat. However, severe issues keep appearing. Breakwater structure blocked longshore sediment transport after the construction immediately. Incident wave angle steers the direction of longshore sediment transport.

Furthermore, sediment will accumulate at one side of the breakwaters, and resulting in accretion. The accretion had reached the fishing port entrance, forming a sand spit that blocks half of the navigation channel so the downdrift does not experience severe erosion [10]. The extended breakwater caused severe erosion at the downdrift. Meanwhile, the navigation channel was always open [11] [12]. The purpose of this paper is to provide an overview of the length of the Jetty to be more effective in stabilizing the Bogowonto river mouth. So that more easily opened by river flow and does not cause excessive erosion on the one side of the Jetty.

2. Materials and methods

2.1. Onshore-offshore movements; significant limit of significant transport

The movement of sediments in the coastal area is mainly due to waves actions. Two fundamental processes have to be considered onshore-offshore movement and longshore transport. The integrated effect of complex onshore-offshore transport processes, continuously varying along with the active profile, determines erosion and accretion along with the profile and at the shoreline.

![Figure 3. Coastal Profile zoning [13]](image-url)
There are three-part beach profiles for seasonal sand beaches movement [13], shown in Figure 3:

1. The Littoral zone lies between shoreline to $d_1$. Intense sediment transport and extreme bottom changes, and a seaward zone of lesser sediment transport by waves.
2. The shoal zone extends from the seaward edge of the littoral zone ($d_1$) to a water depth ($d_2$) where expected surface waves are likely to cause little sand transport; in this zone, waves have neither strong nor negligible effects on the sand bed.
3. Seaward of the shoal zone lies the offshore zone, where surface wave effects on the bed are usually negligible.

An analytical approximation gives the limit of significant sand movement $d_1$ is [13]:

$$d_1 = 1.75(H_s)_{0.137} \text{ and } d_2 = 2d_1$$ (1)

Where:
- $d_1 = \text{is the outer limit of the littoral zone (water depth below low water level), where maximum water depth for nearshore erosion by extreme (12 hours per year) wave condition}$
- $d_2 = \text{is the outer limit of the shoal zone, where maximum water depth for motion initiation by median wave condition}$
- $(H_s)_{0.137} = \text{is the local significant wave height with a frequency of exceedance of 0.137% (12 hours per year)}$

### 2.2. Classification Jetty Length

Three types of jetties length classification have been identified [14] i.e.: (1) Long jetties; the jetty length is longer than the surf zone width (the tip of jetties lies outside the surf zone). (2) Medium jetties; the tip of jetties lies in the breaking zone, extending from low water spring. (3) Short jetties; the tip of jetties lies around a low water spring.

The data collection has been done through the survey for this research to get both primary and secondary data.

### 2.3. Wave and Tide

Wave data is obtained from the Bali beach conservation project (JICA, 1989) and the Tipar drainage project (BCEOM, 1993). Those wave data can be seen in Table 1 and Table 2, while the result of the topographic survey can be seen in Figure 4.

#### Table 1. Wave rose for Indian Ocean (South of Bali)

| Wave Height | N  | NE | E  | SE | S  | SW | W  | NW | Total |
|-------------|----|----|----|----|----|----|----|----|-------|
| 0-1         | 0.50 | 2.50 | 4.29 | 4.67 | 3.30 | 2.54 | 0.60 | 0.50 | 18.90 |
| 1-2         | 0.30 | 0.80 | 7.86 | 9.89 | 20.27 | 7.79 | 4.64 | 1.43 | 52.98 |
| 2-3         |    |    | 3.66 | 4.48 | 7.54 | 5.07 | 2.46 | 0.97 | 24.18 |
| >3          |    |    |    | 0.56 | 1.89 | 1.50 |    |    | 3.95  |
| Total       | 0.80 | 3.30 | 15.80 | 19.60 | 33.00 | 16.90 | 7.70 | 2.90 | 100.00 |

Source: U.S. Navy-Marine Climate Atlas of The World (120 years data)
Table 2. Wave frequency distribution, South of Java Tipar River Mouth (BCEOM, 1993)

| Wave height, H (m) | Wave Frequency (%) |
|--------------------|-------------------|
|                    | 1989 | 1992 |
| 0.0<H<0.5          | 7.16 | 18.41 |
| 0.5<H<1.0          | 41.90| 44.78 |
| 1.0<H<1.5          | 29.70| 33.00 |
| 1.5<H<2.0          | 14.08| 3.20  |
| 2.0<H<2.5          | 4.88 | 0.10  |
| 2.5<H<3.0          | 1.68 | 0.01  |
| 3.0<H<3.5          | 0.40 |       |
| 3.5<H              | 0.20 |       |

From Table 1, it can be concluded that the dominant wave directions are East, Southeast, South, and Southwest. Extreme wave height analysis (highest wave height each year) is used to estimate the return period of significant wave height. The results of the significant wave height return period are shown in Table 3.

Table 3. The return period of significant wave height (the Indian Ocean, South of Bali Island)

| Return Period (Year) | Actual Observation (Kuta beach) (m) | Wave Forecasting Ngurahrai Airport (m) | U.S. Navy Statistic Data (m) |
|----------------------|-------------------------------------|---------------------------------------|------------------------------|
| 1                    | 3.03                                | 4.09                                  | -                            |
| 5                    | 4.13                                | 5.01                                  | 2.70                         |
| 10                   | 4.53                                | 5.37                                  | 3.40                         |
| 30                   | 5.16                                | 5.75                                  | 4.50                         |
| 50                   | 5.44                                | 5.91                                  | 4.95                         |
| 100                  | 5.80                                | 6.12                                  | 5.40                         |
| 120                  | 5.89                                | 6.17                                  | 5.70                         |

Figure 4. Bathymetry of Glagah-Congot Area
2.4. Minimum Discharge
The Bogowonto River is included in the low discharge category, as presented in Table 4. In dry season conditions, the river mouth with the low discharge category will always close quickly.

**Table 4. River Type at South Java Rivers**

| River Type            | South Java Rivers          |
|-----------------------|----------------------------|
| High Discharge        | Serayu, Progo              |
| Medium Discharge      | Lukoulo, Wawar, Opak       |
| Medium-Low Discharge  | Serang                     |
| **Low Discharge**     | Cokroyasan, Bogowonto      |
| Adjacent Headland     | Ijo, Telomoyo              |
| Mixed                 | Tipar                      |

Source: Java flood control project (1995)

The characteristics of the river entrance and lagoons for each river type are summarized in the following table.

**Table 5. River entrance and lagoon characteristics**

| River Type          | Flow | Status of entrance (Dry season) | Closure | Rate of annual entrance movement | Lagoon | Tidal Prism Contribution to openings |
|---------------------|------|---------------------------------|---------|----------------------------------|--------|-------------------------------------|
| High Discharge      | High | Open                            | N/A     | Small                            | Short  | Low                                 |
| Medium Discharge    | Medium| Closed                          | Slow    | High                             | Long   | High                                |
| Medium-Low Discharge| Medium-Low| Closed                    | Medium  | Medium                           | Medium | Medium                              |
| Low Discharge       | Low  | Closed                          | Quick   | Stable                           | Small  | Low                                 |
| Adjacent Headland   | N/A  | Open                            | N/A     | Stable                           | None   | Low                                 |
| Mixed               | Low  | Closed                          | Quick   | Stable                           | Small  | None                                |

Source: Java flood control project (1995)

In the case of the Bogowonto river mouth, most people think that with the construction of the double Jetty, the river mouth will always be open. This opinion is not entirely true. Suppose the discharge of the Bogowonto river mouth during the dry season is not too small, for example. In that case, ten m$^3$/s $<$ Q$_{\text{min}}$ and the longshore sediment transport is not so large, then this opinion is correct. However, if the discharge of the Bogowonto river mouth is close to zero (Q$_{\text{min}}$ $<$ 5.0 m$^3$/s), the river will remain closed (Figure 5 and Table 6).

The closed mouth of the Bogowonto River will seriously endanger the YIA area, as it causes flooding in the airport drainage network. Therefore, the opening mechanism for the Bogowonto river mouth cannot be left entirely to the existence of the double Jetty. However, a mechanism needs to open the closure linked to "operation and maintenance" activities.

Base on the Java flood control project (1995), the results of observations in several river estuaries in the south of Java show that the river mouths in southern Java will remain open if the minimum discharge ranges from 5.0 to 10 m$^3$/s. The following table shows that the Bogowonto river is included in the low discharge category. The river's mouth is always closed during the dry season.
3. Result and Discussion

3.1. Longshore Sediment Transport

In the sediment transport calculation, a simplification of the coastline layout and the direction of the waves is carried out, as shown in Figure 6. Wave height, period, and probability are based on JICA data with a coastal slope of 1:50.

\[ S = p A H_0^2 C_0 K_{frb} \sin(\alpha_{br}) \cos(\alpha_{br}) \]  

(2)

where \( S \) - longshore sediment transport, \( A \) – CERC coefficient, \( p \) – a percentage of wave occurrence, \( H_0 \) – significant deepwater wave height, \( C_0 \) – deep water wave celerity, \( K_{frb} \) – refraction coefficient at breaking area, \( \alpha_{br} \) – angle of an incoming wave at breaking area.

### Table 6. Minimum Discharge

| No. | River  | \( Q_{\text{min}} \) (m³/s) |
|-----|--------|-----------------------------|
| 1   | Progo  | 10.2                        |
| 2   | Bogowonto | 2.5                    |
| 3   | Cokroyasan | 1.4                     |
| 4   | Wawar  | 4.0                         |
| 5   | Lukulo | 2.6                         |
| 6   | Serayu | 16.0                        |
Table 7. Sediment Transport at Glagah-Congot

| Directions of Deep Water Wave (Hs) | Significant Wave Height (m) | Sediment Transport \((10^3 \text{ m}^3/\text{year})\) | Total Sediment Transport \((10^3 \text{ m}^3/\text{year})\) | Directions of Sediment Transport |
|-----------------------------------|-----------------------------|---------------------------------|-----------------------------|--------------------------------|
| South East                        | 0.5                         | 5.2                             | 575                         | West                           |
|                                   | 1.5                         | 184.6                           |                             |                                |
|                                   | 2.5                         | 298.0                           |                             |                                |
|                                   | 3.5                         | 87.2                            |                             |                                |
| South                             | 0.5                         | 1.4                             | 449.3                       | West                           |
|                                   | 1.5                         | 147.7                           |                             |                                |
|                                   | 2.5                         | 189.2                           |                             |                                |
|                                   | 3.5                         | 111.0                           |                             |                                |
| Total Sediment Transport to West  | 1024.3                      | West                            |                             |                                |
| South West                        | 0.5                         | 5.1                             | 731.0                       | East                           |
|                                   | 1.5                         | 148.4                           |                             |                                |
|                                   | 2.5                         | 340.5                           |                             |                                |
|                                   | 3.5                         | 237.0                           |                             |                                |
| Total Sediment Transport to East  | 731.0                       | East                            |                             |                                |
| Net Transport                     | 293.3                       | West                            |                             |                                |

Based on the Indian Ocean wave data (JICA, 1989) and by applying the CERC formula, the rate of sediment transport at the Glagah-Congot area can be estimated as follow (see Table 7): to the West direction is about 1.024 million m³/year and to the East is about 0.731 million m³/year (BBWS SO, 2013). From this sediment transport rate, we can determine that the net of longshore sediment transport at Glagah-Congot is about 0.293 million m³/year. It should be noted that the calculation of this sediment transport is of low accuracy, considering that the wave data (direction, wave height, event process) is inaccurate. The formula is still in the process of being developed.

3.2. The coastal sediment movement zone

As mentioned before, \(d_1\) is the outer limit of the littoral zone where intense sediment transport and extreme bottom changes occur. Using Kuta beach actual observation data, the wave height can be determined with a return period of 2 or 3 years. \((H_s)_{0.137}\) determined based on Table 3, where \((H_s)_{0.137} \approx (H_s)_{3 \times 2} = 7 \text{ m}\) and \(d_2 = 2 \times 7 = 14 \text{ m}\). Based on that estimation, if the tip of the Jetty is still at an elevation of up to -7 m, then at that location, there is still intense and significant sediment transport of material, both longshore transport and cross-shore transport.

3.3. The length of jetty Vs deposit

The bathymetry measurement results (Figure 4) are used to determine the detained sediment that can be accommodated by the Jetty based on the length of the Jetty (Table 8 & Figure 7).

Table 8. The length of jetty Vs sediment that detained

| Jetty Length, \(L\) (m) | Depth, \(d\) (m) | The width of deposit (coast side), \(B\) (m) | Cross-section area, \(A\) (m²) | Volume \(V\) (m³) |
|-------------------------|----------------|---------------------------------|-----------------------------|----------------|
| 100                     | -6.0           | 567                             | 375                         | 71.000         |
| 150                     | -7.5           | 850                             | 713                         | 202.000        |
| 200                     | -9.0           | 1134                            | 1125                        | 425.000        |
| 250                     | -10.5          | 1417                            | 1612                        | 761.000        |
| 300                     | -12.0          | 1700                            | 2175                        | 1.256.000      |
The condition of the south coast of Yogyakarta and Central Java during the dry season, the direction of the waves coming from the Southeast, which is usually called the east season. Longshore sediment transport is 1.024.300 m$^3$, where Bogowonto river is at the minimum discharge (2.5 m$^3$/s). With a combination of a small tidal range, low river discharges in the dry season, and large sediment transport, the river mouth close quickly. The problem gets worse if that year is a dry year where the dry season is longer.

If we use a jetty with a 7.5 m length, then the amount of sediment detained due to the Jetty is 202.000 m$^3$. From Table 7 calculation, during the east monsoon, longshore sediment transport to the west is 1.024.300 m$^3$. Then the sediment that passes in front of the tip of the Jetty is $1.024.300 - 202.000 = 822.300$ m$^3$ (during the east monsoon). Based on the estimation, it can be revealed that the Jetty structure (short or medium) cannot guarantee that the river mouth is always open all year.

**Table 9. The criteria for choosing the type of Jetty in the mouth of the Bogowonto estuary**

| No  | Criteria                                             | Short Jetty | medium Jetty | Long Jetty                                                                 |
|-----|------------------------------------------------------|-------------|--------------|---------------------------------------------------------------------------|
| 1.  | The jetty functions                                  | - River mouth stabilization | - River mouth stabilization | - River mouth stabilization |
|     |                                                      | - Maintain the shoreline on the west side of the Jetty | - Maintain the shoreline on the west side of the Jetty | - Maintain the shoreline on the west side of the Jetty |
| 2.  | The depth of the jetty tip                           | 0.00 s/d -3.0 m | -3.0 m/s/d -8.0 m | -8.0 m s/d -15.0 m |
| 3.  | The ability to detain sediment                       | Sediment is not detained | Sediment is not detained | Much sediment retained (YIA area no longer prone to flooding, but severe erosion at downstream) |
| 4.  | Negative effects of jetty construction              | nothing (environmentally friendly) | a little accretion at the updrift and erosion at the downdrift | There has been significantly accretion at the updrift and erosion at the downdrift |
| 5.  | Construction costs                                  | Relatively cheap ± 150 s/d 200 billion rupiah | Expensive ± 200 s/d 500 billion rupiah | Very expensive ± 500 s/d 800 billion rupiah |
| 6.  | Operation and maintenance                           | Necessary, relatively cheap | Necessary, relatively cheap | Navigation channel maintenance is not required, but erosion treatment downdrifts are relatively expensive. |
4. Conclusions
In order to determine the jetty length, several considerations are needed based on previous descriptions (Table 9). The consideration of the jetty length chosen was primarily intended for flood control at the mouth of the Bogowonto river. Based on these descriptions, a short jetty can be chosen as the structure to be applied at the Bogowonto river mouth. The selection of this short jetty was carried out so that longshore sediment transport was not obstructed. The jetty also stabilizes the river mouth and prevents the coastline at the east jetty area from erosion. Several things must be done for the double jetty to optimally in controlling flooding, i.e.:
1. Operation and maintenance periodically, especially during the dry season, by moving sand that reaches the tip of the Bogowonto jetty to the west of the west side jetty.
2. If operation and maintenance activities are not carried out periodically, then at the end of the dry season (when a high discharge was foreseen), villagers dug a guide channel using a backhoe with a depth of about 1.50-2.0 m and a width of about 2.0-3.0 m.

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