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HYDRODYNAMICS AND SEDIMENT CHARACTERISTICS ON A BATHYMETRICALLY-CONTROLLED RIP CHANNEL IN PANGANDARAN BEACH

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Sari – *Rip current* adalah fenomena hidrodinamika yang terjadi di sepanjang pantai dan penting untuk dipahami karena keunikannya dan berkaitan dengan faktor keselamatan khususnya di daerah wisata. Dalam studi ini dikaji mengenai *rip current* yang disebabkan oleh faktor batimetri (*bathymetrically controlled*) yang biasa ditemui di pesisir selatan Provinsi Jawa Barat. Fenomena ini mempengaruhi karakteristik sedimen, khususnya pada bagian ujung kanal yang biasanya memiliki sedimen yang lebih kasar dibandingkan dengan sedimen di tepi pantai akibat lebih besarnya gesekan dasar. Interaksi yang kompleks pada fenomena ini membutuhkan investigasi yang lebih lanjut, oleh karena itu studi ini dilakukan dengan lokasi studi Pantai Pangandaran yang terkenal akan *rip current*-nya. Observasi lapangan telah dilakukan untuk mengumpulkan sampel sedimen dalam arah tegak lurus garis pantai yang menunjukkan karakteristik yang lebih halus di tepi pantai dan bertambah kasar ke arah lepas pantai dengan rentang diameter antara 0,35 hingga 0,37 mm. Sebagai tambahan, simulasi numerik sederhana juga dilakukan untuk menggambarkan fenomena ini. Hasilnya menunjukkan bahwa arus paling kuat memiliki kecepatan sekitar 3 meter per detik, yaitu pada bagian ujung kanal. Hal ini berbanding lurus dengan gesekan dasar yang dihasilkan. Faktor gesekan dasar juga menggambarkan proses pergerakan arus dari sisi menuju kanal hingga akhirnya bergerak menuju ujung kanal. Variasi gesekan dasar ini juga menyebabkan adanya perbedaan karakteristik sedimen di sepanjang transek menuju arah lepas pantai.

Kata kunci: Makalah, ringkasan, informasi, penelitin

Abstract - *Rip currents are hydrodynamic events that form vary alongshore depend on local setting of its bathymetry feature and forcing. When it occurs, it is important to understand the process in order to prepare safety issues on recreational beaches. Bathymerically-controlled rips are the focus in this study, as this type is commonly found on Indonesia's coastal areas, particularly in south coast of West Java. This unique hydrodynamics feature affects sediment characteristic, particularly at the rip channel as the lower part (far from shore) tends to have coarser sediment due to larger friction. Such complex interactions need thorough investigation; therefore, a study was conducted in Pangandaran which well-known for its rip currents. Field observation was made to collect sediment sample on cross shore direction which shows finer sediment on upper rip channel and coarser sediment on the lower part with diameter size of 0.35 mm and 0.37 mm, respectively. In addition, simple simulations were also made to illustrate rip current movement on a channel. The result shows that in the strongest current area with over than 3.0 m/s current speed, i.e. on the lower part of rip channel, bed shear stress is found to be the strongest. It is been noticed as well that the bed shear stress forms a pattern which delineate overall movement of a rip current. Furthermore, the variation of bed shear stress is revealed as the main cause of sediment distribution along the cross-shore direction. Therefore, this simple approach qualitatively illustrates the dynamics of rip current phenomenon.*

Key words*: rip current; hydrodynamics; morphology; sediment; Pangandaran*

1. INTRODUCTION

The presences of concentrated seaward-flowing currents are observed in many beaches. This water movement, i.e. rip current, is one of many processes that happen in the coastal area (Castelle et al., 2016). The understanding of this phenomena is necessary, as rip currents often occur in tourism beaches, especially the one directly facing open seas, for instance, the southern coast of West Java. Early studies reported that rip current velocities observed around 0 - 1 m/s (0 - 2 knots) (MacMahan et al., 2006), which is life-threatening to swimming tourists. However, over the last decades, many studies have shown varieties of rip current pattern, therefore, parallel swimming may not help tourists to survive (Castelle et al., 2016;

Pitman et al., 2016). On the scientific sides, rip current system has unique hydrodynamics features as well as its impact to surrounding environment.

There are three categories of rips which are, boundary-controlled rips (occur on lateral boundaries), hydrodynamically-controlled rips (occur on beaches with uniform bathymetry alongshore, and also are transient in space and time), and at last, bathymetry-controlled rips that are forced by hydrodynamics variation driven by bathymetric changes (Castelle et al., 2016). Rip current strength varies mostly based on wave energy, but in a bathymetrically controlled rip, water depth also has an important role (MacMahan et al., 2006). Rip current system is an integration of nearshore circulation that represent seaward transport of water and sediment (Aagaard et al., 1997). Many natural aspects, for instance, morphology, hydrodynamics, and sediment transport control rip system in the term of formation and characteristics (Brander, 1999).

As rip current varies because of hydrodynamics factor, it also affects the surrounding environment, such as the sedimentation characteristics. A rip channel is formed as the results of the perturbation from the high velocity of rip currents. For some rip channels, the only developed part is the neck because of its intense current, while others also have extensive smaller channel alongshore which are located on the stronger feeder's side. In the term of its bed characteristic, irregularities can be easily found because of the strong current (Shepard & Emery, 1971). Rip current can form the channel morphology in the term of an increase in channel depth and a reduction in channel width (Brander, 1999).

Field investigation of rip currents have been known for its difficulties due to their perilous natural behavior, hazardous impact on the coastal environment and the migration of its channels (Sabet & Barani, 2011). Therefore, to overcome this problem, combinations of observation methods are known to be used, not only depending on field observation. Many researches of rip currents have been conducted using various approaches, for instance, an approach of modelling was made by combining Eulerian and Lagrangian methods by using static current meters and drifters (Gallop et al., 2018). On the other hand, there was also field measurements and numerical modelling combination to reproduce rip currents by considering the tidal cycle effect (Austin et al., 2014). Meanwhile, there was also a study that focused on investigating rips impact to morphology by calculating the non-linear aspect while coupling flow model and sediment transport (MacMahan et al., 2008). More recently, remote sensing was also introduced as the alternative method to investigate the rip currents (Haller et al., 2014; Hunter & Hill, 1980). Therefore, a proper combination of observation methods needs to be conducted to thoroughly understand rip current system and its effect on sediment characteristics of the environment.

2. DATA AND METHODOLOGY

The study was conducted in the southern coast of Java, to be exact along Pangandaran Beach. Rip currents frequently occur in this location because it is directly facing the Indian Ocean made the coastal water has high wave height characteristic, which is known as the main source of rips. Moreover, it also has a large possibility to experience storm and longer period wave. Based on a brief measurement of waves on two locations in Pangandaran Beach, it is known that the wave height was around 1.3 m and 1.5 m with the period of 3.7 to 4 second. It was found that the average width and length of rips in Pangandaran were 98 m and 300 m, respectively, with the distance between the rips were 100 to 500 m. It was also stated that almost the rip occurrences were found on the center of the bay (Sandro et al., 2018).

The data for this study were collected during a field observation conducted on 14 November 2017. To establish basic understanding of the beach morphology, sediment samplings were done on a cross-shore direction along a rip channel to portray how the current affects sediment distribution. In total, 22 samples were taken in various points, i.e. left, middle, and right part of the rip channel, at seabed surface

(< 8 cm of depth). The samples were analyzed to define the characteristic of sediment at the study location by using ASTM D422-63 method. This method quantifies the determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 μm was determined by sieving while the ones that smaller was quantified using a hydrometer in a sedimentation process. In addition to the sample analysis, measurements of shoreline slope were also conducted, particularly at the center of the rip channel. It becomes the most important analysis as rip currents on the study location tends to be a bathymetrically controlled rip instead of other types.

Another important part of the experiment was aerial observation. As rip channels tend to shift alongshore, initial observation using satellite images was conducted first in order to detect hot spots of the rip current. Then, a location of rip channel was picked based on its significance in the term of dimension compared to others. At the pre-determined location of the rip channel, a drone was used to capture rip current behavior during different tidal phases to understand how the rip flows daily. The drone was flown using DroneDeploy app which enables us to cover larger area by determining tracks for the drone to follow, then, it combines series of images along the track to be a composite of larger area picture without decreasing its resolution. Moreover, the images were also able to illustrate the dimension and shape information of the rip channel based on georeferenced process.

To comprehend the investigation of rip-current in the channel, a numerical simulation test has been done using Delft3D-Flow. The numerical model represented local feature of a rip channel as the model was simulated on a small scale to specifically delineate the condition of study site. In general, the fluid condition is assumed as non-compressible and the input has been set to wave driven current mode. The governing equations that were used in the model are depth-averaged continuity equation and momentum equation. The continuity equation used in hydrodynamic modeling is obtained from Luijendijk (2001):

$$\frac{\partial \eta}{\partial t} + \frac{\partial (d+\eta)u}{\partial x} + \frac{\partial (d+\eta)v}{\partial y} = 0 \qquad (1)$$

The momentum equation used in hydrodynamic modeling in the x and y directions, respectively, are:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \eta}{\partial x} - fv + \frac{\tau_{bx}}{\rho_w (d+\eta)} - \frac{F_x}{\rho_w (d+\eta)} - \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = 0 \qquad (2)$$

And

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial \eta}{\partial y} + fu + \frac{\tau_{by}}{\rho_w (d+\eta)} - \frac{F_y}{\rho_w (d+\eta)} - \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) = 0 \qquad (3)$$

with:

d : water depth (m)
f : Coriolis parameter (s^{-1})
$F_{x,y}$: external force on x and y direction (Nm^{-2})
u, v : depth-averaged velocity (ms^{-1})
ρ_w : water density (kgm^{-3})
ν : eddy viscosity coefficient (m^2s^{-1})
η : water elevation (m)
g : gravitation acceleration (ms^{-2})
τ_{by} : bed shear stress (Nm^{-2})

3. RESULTS

The present study demonstrates the importance of combining field observation and numerical modelling in understanding rip current system. The field observation has been accomplished perfectly by following the standard operating procedure and observation methods. The aerial observation by using drone was conducted to observe the current pattern of the rip, whereas the seaward-current is visibly passing the rip's neck. It can be seen on **Figure 1** that there is an image of rip current from the aerial observation.

Firstly, remote observation by utilizing satellite image was conducted to determine the location of biggest rip as there are many rips on the study location which was obtained from Google Earth software. Then, by conducting aerial observation using drone on the location, more detail data can be obtained. The images indicate a relatively large rip along the beach. The rip formation has width of 150 meters and length of 200 meters, with slightly slanted feeders from the east. Due to its large dimension, the understanding of rip current pattern is important as it generates high-energy currents which easily affects the condition of the shore. Based on the images, there was a seaward current that cut through the waves which formed a channel with slanted end to the west.

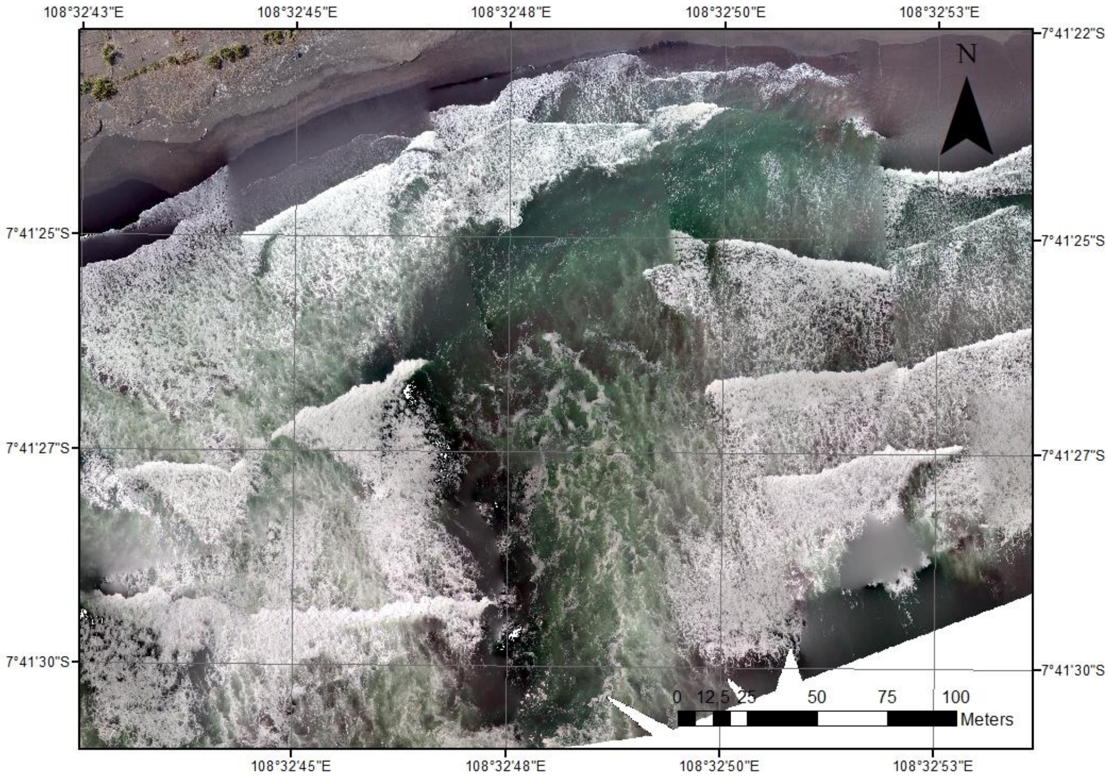

Figure 1. Rip-current formation based on aerial observation by using drone in the present study

To comprehend the understanding of rip current behavior, a case study by using a numerical model, i.e. Delft3D, has been conducted. There were two main aims to achieve from the model experiment, which were to confirm the rip current pattern and formation whether it is similar to the theory and field observation result, and to understand the pattern of bed shear stress. The domain of the model was determined to represent a particular rip channel, which was one of the biggest.

As a matter of fact, the model result was comparatively similar to the field observation. In addition, the result was also in agreement with the sediment sample analysis and bathymetric profile. In the matter of current pattern, the model showed that the feeder current from both sides generated the rip, which reached its peak on the center of the channel (**Figure 2**).

It can be seen on the figure that the rip current speed reached over than 2 m/s. It is comparatively similar to the findings of MacMahan et al. (2008) which conducted field observations of rip current. The current energy caused strongest erosion which was illustrated by the bed shear stress parameter. In short, the result confirmed that in this exact location, i.e. the center of the channel, sediment movement were more dynamic compared to its upper part, causing coarser sediment characteristic.

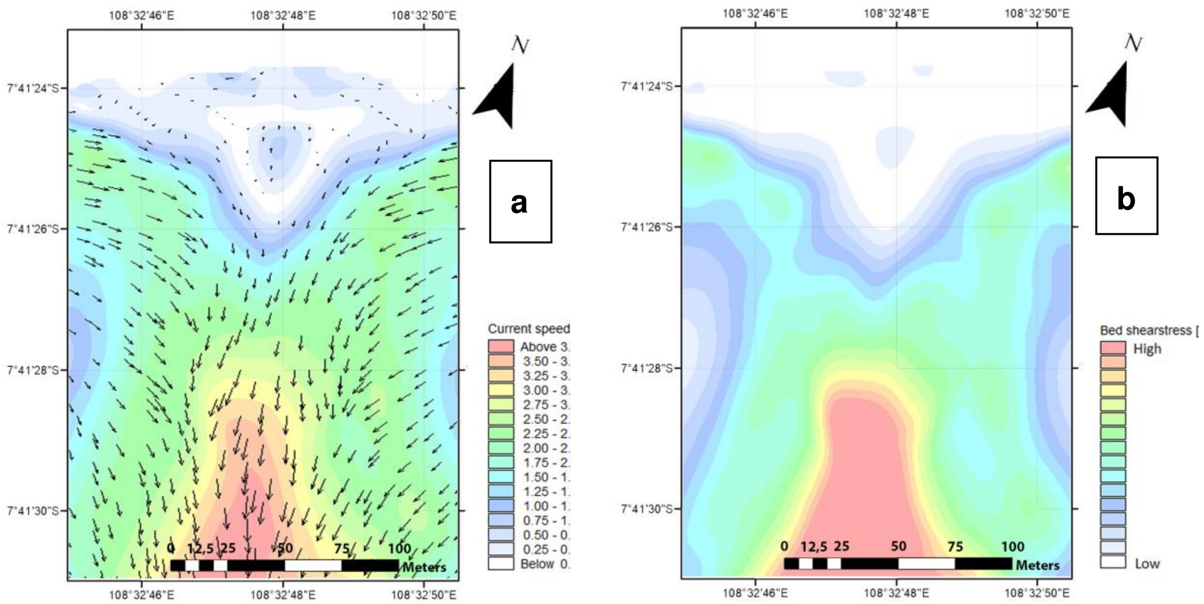

Figure 2. Numerical model results that illustrate; (a) current speed on the rip channel, and (b) bed shear stress due to the rip formation

In this research, the sediment distribution, particularly the D50 parameter, represented the current condition of the environment. Based on the analysis of sediment samples (**Figure 3**), the sediment characteristic varied in the cross-shore direction. On the upper part of the rip, the sediment was finer compared to the lower part. The sediment became gradually coarser which were 0.29 cm to 0.37 cm, as the sampling location became further from the shore. However, the first sample showed an anomaly with diameter size of 0.35 cm that can be neglected as it did not interfere with the general distribution towards the open seas.

As a hydrodynamics process, rip current generated erosion made by the seaward-current. In addition, the variation of current energy played an important role in the sediment characteristic difference. As the current energy was lower on the upper part because it was initially generated, the erosion was not significant, so the upper layer of sediment which was finer still dominated the characteristic. Meanwhile, the lower part of the neck, or its bottom, suffered higher erosion as the current already well-developed, therefore, this location had coarser sediment characteristic as the upper layer with finer sediment was eroded and transported to the sea.

The characteristic of sediment itself mainly determined by local along-shore processes because of its bay shape feature. Moreover, there were not found any rivers with significant size on the research area, only two small rivers along 25 kilometers of shoreline. Therefore, the sediment variation was not affected by external morphological features nor by distant events. However, as the rip current in Pangandaran is a specific bathymetrically-controlled type, the distribution of sediment size may be different compared to other places because of its local erosion event, particularly to coasts with different sediment types. Meanwhile, the whole rip current system mainly dominated by the combination of remote and local hydrodynamics processes, i.e. offshore wave forcing, wave breaking, and rip current flow which generates bed shear stress and local erosion variation, followed by interaction with the coastal morphology, i.e. bathymetry and coastal type.

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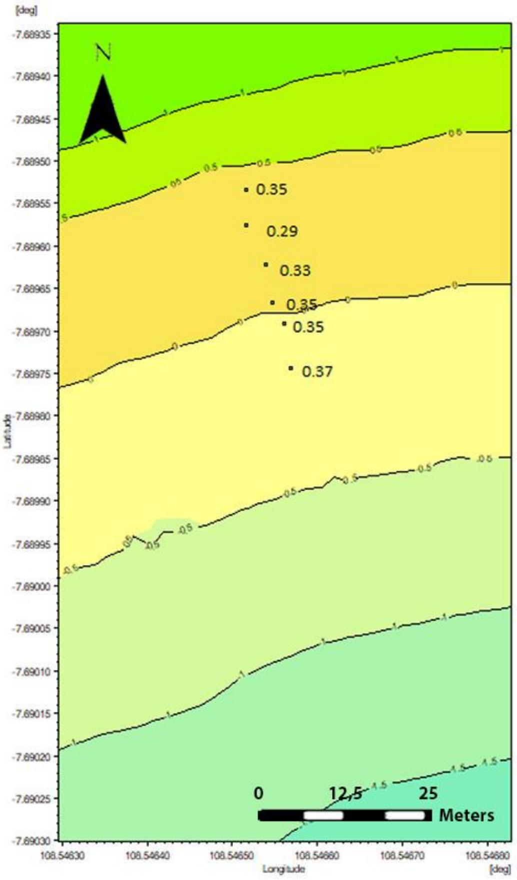

Figure 3. Morphology aspects of the rip channel: cross-shore sediment diameter distribution (in cm), obtained from sediment sample analysis. Contoured layers represent coastal bathymetry from 1 meter above sea level to 1.5 meter below sea level

5. CONCLUSION

Rip current is a unique feature of coastal circulation that is generated from the combination of hydrodynamics and morphological factors. Due to its dimension and current speed, it is considered as a threatening event in the matter of safety in tourism beach, yet also intriguing in the science point of view as it has unique characteristics. Therefore, in this study, combination of direct field observation, i.e. sediment sampling and aerial observation, sediment analysis, and numerical modelling were conducted in Pangandaran Beach to improve the understanding of local rip current mechanism. The field observation has been accomplished perfectly by following the standard operating procedure and observation methods. The study was conducted in a bathymetrically controlled rip that is generated because of morphology characteristics. Based on aerial observation, it was found that the rip's width was 150 meters with whole channel that slanted to the west. Then, the numerical modelling result showed similarity with field observation in the matter of rip formation with the current speed of 2 m/s, 2.5 m/s and 3.0 m/s on its feeder, middle of channel, and head, respectively. The current speed was directly proportional to the bed shear stress that represented erosion intensity on the channel. The sediment diameter was found out to increase in the cross-shore direction, from 0.29 to 0.37 cm which confirmed that the numerical modelling and sediment distribution illustrated the erosion event on channel's bed that reached maximum intensity at the rip's head. Therefore, a rip current system can be concluded as a massive hydrodynamics processes that shares impact to local morphology, e.g. sediment distribution.

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