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Modeling of Sediment Transport Affecting the Coastline Changes due to Infrastructures in Batang - Central Java

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Abstract

The presence of newly-built infrastructures along the coast of Batang, Central Java, has inherent effects on coastal hydrodynamics and natural equilibrium of annual sediment transport near the coastline. Retreating coastline as a result of severe erosion continuously occurs at some locations in recent years. This study aims to calculate the sediment transport behaviour along the coast of Batang, Central Java, by considering the presence of infrastructures. Modeling was done by means of a commercially available software package MIKE21, especially the LITPACK module, developed by DHI Water and Environment, Denmark. The model shows that sediment drift parallel to the coastline occurs primarily within the distance of 300 meters from the coast. From 2010 to 2013, the general trend of sediment transport in the area is that there is a net sediment transport from the west to the east direction in the early months of the year, followed by a shorter period of transport in opposite direction (westward) for a few months. The inbalance of this sediment transport capacity is suspected to be responsible for the changes in coastline morphology in Batang.

Keywords: coastal morphology, sediment, infrastructures, LITPACK, Batang Central Java

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1. Introduction

Coastal areas have a vulnerability to coastal issues such as abrasion, accretion or sedimentation in response to geophysical conditions and or as a result of human intervention such as port construction, development of facilities for tourism and other beach activities. In this regard, the study of the influence of coastal infrastructures to the beach is essential in order to understand the causes of coastal damage. Good planning for mitigation will provide benefits to improve regional competitiveness and increase social welfare.

The objective of this work is to study the effects of coastal infrastructures on the changes of sediment transport behaviour, which eventually will affect the coastal morphology in Batang, Central Java. The assessment is based on computational modeling of hydrodynamics and sediment transport properties in the area, especially the coastal segment between Sigandu and Ujungnegoro, Batang. The study was conducted using a software package developed by DHI, namely MIKE21 for the hydrodynamics, and LITDRIFT module of the LITPACK software for sediment transport modeling.

a. LITDRIFT

LITDRIFT module is part of the software package LITPACK developed by DHI Water & Environment. The software package is based on a sediment transport module (STP) and different coastal and shoreline analyses are available. LITDRIFT simulates the littoral drift or shore- parallel sediment transport. The output from the model is the littoral drift for the individual wave situations and the total sediment budget for the year.

When waves approach a coast they will shoal and eventually break. This causes a release of energy which is used for resuspension of sediment and induction of a shore-parallel current. The physics behind these processes are well known and is integrated into LITDRIFT. Based on input of wave statistics and the characteristics of the coastal profile, it is possible to compute the littoral drift accurately.

The simulations are based on three different types of input:

- A wave climate file including a yearly summary of the incoming waves. The wave height, wave period and wave direction are, among other things, included in the file.
- A profile description. This file includes information on the bathymetry and the sediment characteristics along each profile. This includes the bed roughness and the sediment grain size
- An input file. This file describes the combination of the wave climate file and the profile description as well as the solution technique.

b. Case study: Batang, Central Java

Batang district lies between 6˚51'46" and 7˚11'47" latitude, and between 109˚40'19" and 110˚03'06" longitude. The capital city of Batang has an area of 788.64 km^2. The southern part of the district comprises of mainly hills and mountains such as Dieng plateau and Mount Prau, while in the northern part lies a fairly small coastal plain. Adjacent counties are Wonosobo and Banjarnegara districts in the south, Kendal in the east, and the city of Pekalongan in the west, as shown in Fig.1.

According to Sigandu-Ujungnegoro Masterplan[1], the coastal area is described as having a slope of 0.5% in Kidang Lor and 0.33% in Ujungnegoro. Based on measurement results by[2], it was found that the high and low tides occur twice with different periods[2]. The ocean current is about 0.03 m/sec at the lowest, and the highest is 0.25m/sec with an average speed of 0.11m/sec. Previous studies stated that the wave height in the area varies between 0.78 to 1 m.

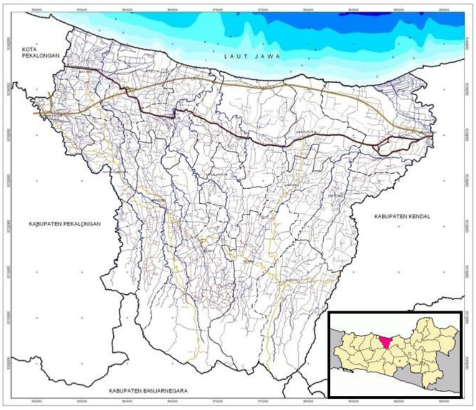

Fig.1. Batang District area (source: Pemda Kabupaten Batang)

Satellite images from Google Earth have revealed significant coastline changes in Batang from 2006 to 2013. Fig 2 shows retreating coasline, especially near Pelabuhan Niaga, Sigandu.

Fig.2. Sigandu-Ujungnegoro coasline changes from 2006-2013 (source: Google Earth)

2. Outline of The Methods

Three main steps were taken in this study:

• Modelling of the wave transformation from offshore to nearshore of Batang, Central Java.
• Analysis of sediment transport along Batang coastline.
• Analysis of possible coastal morphological impacts due to littoral drift.

Local wave model, along with bathymetry and sedimentological conditions are required to estimate sediment drift by computations with a numerical model. This requires the understanding of the offshore wave conditions in the area.

3. Nearshore Wave Modeling

The determination of sediment transport processes in Batang requires the transformation of the wave conditions from the offshore into the nearshore areas. Regional wave modeling is carried out in order to incorporate the most relevant physical wave processes and to transform offshore waves (provided by BMKG Stasiun Pelabuhan Tanjung Emas Semarang) into Batang area. These wave conditions were then applied as boundary conditions that provide input for the computations of the sediment transport in the study area. This regional model can also provide wave information on the areas not affected by the coastal structures such as breakwaters, groins and so on (where diffraction is not relevant). This information will allow determination of the sediment transport conditions that will provide important information for the detailed 2D morphological assessment of Batang Beach to be carried out later on the study. This wave transformation has been undertaken using DHI's two dimensional (2D) numerical wave transformation model MIKE21 SW (Spectral Wave Model)[3] which propagates waves from deep water into nearshore areas. The model simulates the growth, decay and transformation of wind-generated waves and swell in offshore and nearshore areas.

a. Offshore wave data

Fig.3. Overview of Batang beach and Exposure to Offshore Waves

Batang beach is exposed to the incoming waves due to a short-to-medium fetch from Java Sea (Fig.3). Batang off-shore wave data were generated from Wind Data provided by BMKG Semarang from 2010-2013. The generated off-shore wave model is assumed to have a good representation of general wave climate conditions in Batang area. Fig 4 shows a wave rose that represents a consistent pattern from year to year, with the majority of the wave energy propagating from the Northwest with a second predominant direction from the East.

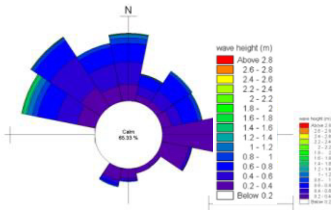

Fig 4. Offshore wave rose 2010 – 2013

b. Model Setup

MIKE 21 SW utilises a calculation mesh that requires a good representation of the coastal region around Batang. A model mesh was established on the basis of data provided by the BPDP Topography and Bathymetry Survey Teams, and available sea charts for the area. The extension and direction of the applied model mesh is shown in Fig 5.

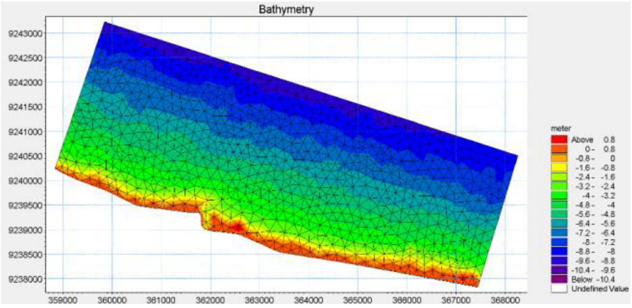

Fig.5. Model mesh applied in the nearshore wave transformation modeling

The simulations have been carried out with assumed bottom friction of 0.004m, and the model was run throughout the period from 01 January 2010 to 29 October 2013.

c. SW Modeling Results

In order to illustrate the regional wave conditions, examples of output from the wave models for two wave directions (60 and 330 deg N) are presented in Fig 6 and 7.

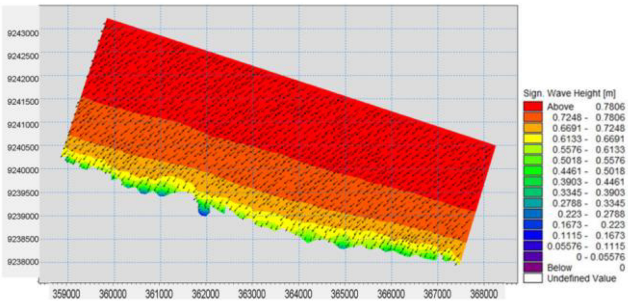

Fig 6. Output from regional wave simulation, offshore MWD = 60 degN

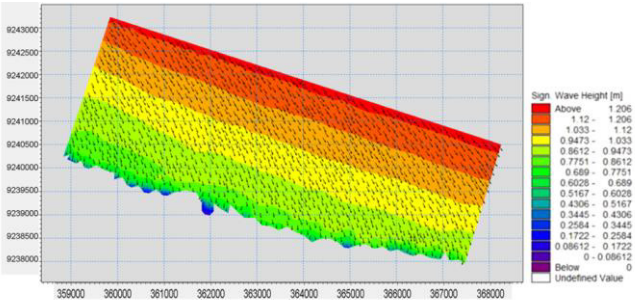

Fig 7. Output from regional wave simulation, offshore MWD = 330 degN

d. Nearshore Wave Roses

For transformation of the offshore time series into the nearshore areas, wave parameters were extracted at water depth of approximately -8 m at different locations along Batang beach. Fig. 8 shows the location of the extraction points, representing 4 main locations of interest, which are (from west to east) the western groyne, Sigandu, Dolphin center and UjungNegara. These points are the toes of the cross-shore profiles used for the calculations of littoral drift which will be discussed later. Meanwhile, Fig. 9 shows wave roses for the significant wave height (Hs) at the extraction points. The extraction of data in these points were carried out during the establishment of the local wave model.

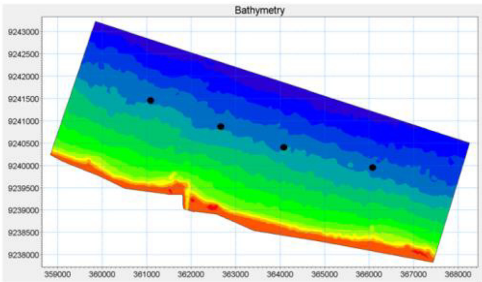

Fig. 8. Location of the 4 nearshore extraction points at -8 m

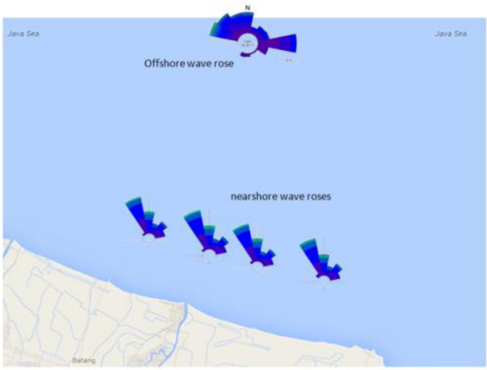

Fig.9. Overview of the offshore and nearshore wave roses

4. Littoral Transport

When waves approach the coast they will break and release their energy. As a consequence of this, sediment may be resuspended and a wave-driven current along the coast will be generated. The littoral drift was computed in 4 profiles along the coast. The coastal profiles were obtained from the field survey conducted in October 2013.

The domain of interest covers an area of about 8 km long (from the western groyne to Ujung Negara) and 2 km wide (from the coastline seaward). Along the stretch, the littoral drift is modelled through 4 individual shore normal transects. The littoral drift is modelled based on detailed wave climates, bathymetry, sea-bed, and sediment properties along the cross-shore profiles. Computation and analysis of the littoral drift (longshore sediment transport) were carried out. Where possible, morphological changes are discussed based on the changes in littoral drift.

a. Cross-shore profiles

The four profiles were constructed based on the field survey, at the locations where sediment samples were gathered. In computational domain, the bathymetry of study area and the cross-shore profiles are illustrated in Fig 10.

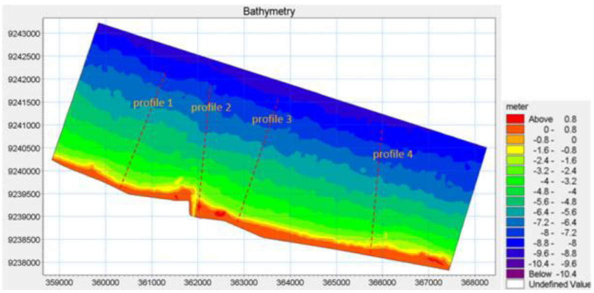

Fig 10. Bathymetry of study area indicating locations of investigated profiles

The characteristics of the individual computation profiles are tabulated as follows:

Table 1. Overview of Profiles used for Computation of Littoral Drift

Profile ID	dX (m)	Extend (grid)	Depth (m)	Shore normal orientation (deg from North)	Length (m)
Profile 1	10	250	7.7	25	2500
Profile 2	10	250	8.2	5	2500
Profile 3	10	250	8.5	25	2500
Profile 4	10	250	8.3	10	2500

b. Bed parameters

Median grain size (d_{50}) and geometrical spreading factor were obtained from the field data analysis results. The d_{50} values vary from about 0.01 to 0.3mm, while the spreading factor of grain sizes range from 1.5 to about 8. However, the hydraulic bed roughness of 0.004 m is assumed for all profiles.

c. Waves

Wave information was extracted at the offshore end of each coastal profile, which are the nearshore wave models resulted from wave modelling earlier. The wave-event duration models were computed from 2010 through 2013. In the LITDRIFT model[4,5,6], the longshore sediment transport is computed for each of the different wave situations and weighed according to the percentage by which the wave condition occurs.

d. Model setup

The model was set up using the parameters given in Table 2. The sea currents and wind driven currents (in the surf zone) are not included as the wave driven currents dominate the other phenomena in the present case. A uniform sediment description was used as the sediment drift calculations will be based on the mean grain diameter d_{50} and mean fall velocity, as given in the profile file. The critical shields parameter (the relation between de-stabilising and stabilising forces on a grain at the bed) is set to 0.045. Sediment porosity value of 0.4 was used. Concerning the wave theory it was chosen to use the Stokes approach with a wave spreading factor of 0.5. The wave spreading factor is a reduction factor on the wave radiation stresses to account for directional waves (compared to unidirectional waves). The factor 0.5 is typical for wind waves on a sandy beach.

Table 2. Setup Characteristics for the Litdrift Model

Parameter	Values
Wave set-up calculation included	Yes
Tidal and meteorological currents included	No
Wind included	No
Sediment description	Uniform
Number of fractions	--
Water temperature	25 °C
Ripples included	Yes
Sediment density	2.65 g cm^{-3}
Critical Shields parameter	0.045
Sediment porosity	0.4
Wave theory	Stokes
Wave spreading factor	0.5
Description of bed concentrations	Deterministic

Fig. 11 describes –as an example- the properties of Profile 1 (at the location of the western groyne), showing the cross-shore bathymetry profile and the corresponding wave rose at the toe of Profile 1. The values are based on measurements, surveyed using echo soundings from a fishing boat and the positioning was based on GPS.

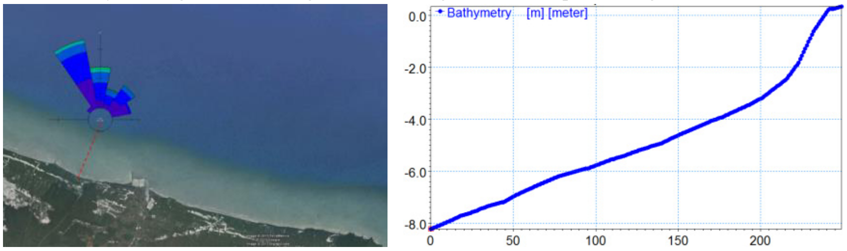

Fig 11. Wave rose and cross-shore bathymetry profile at Profile 1

e. Modeling Results

i. Littoral current and sediment transport

Fig 12 to Fig 19 show the distribution of littoral current and sediment transport along each profile for both dominant wave directions.

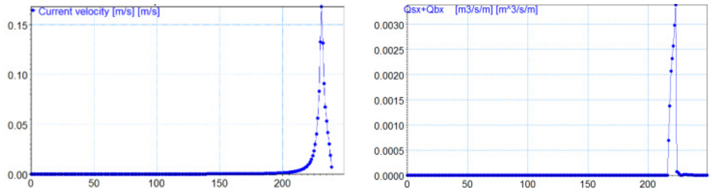

Fig.12. Longshore current (left) and sediment transport (right) crossing Profile 1 for northwestern wave (Hs= 0.8 m)

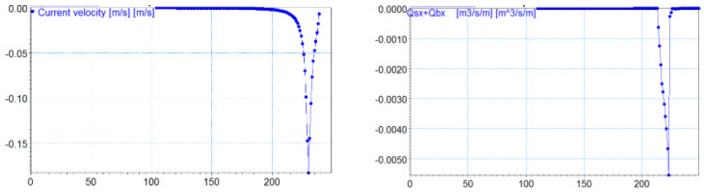

Fig.13. Longshore current (left) and sediment transport (right) crossing Profile 1 for eastern wave (Hs= 0.8 m)

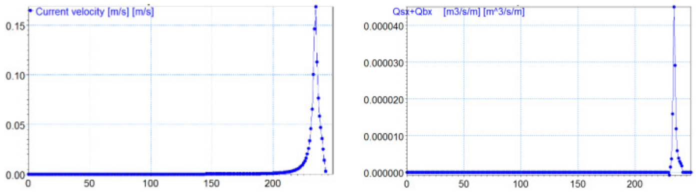

Fig.14. Longshore current (left) and sediment transport (right) crossing Profile 2 for northwestern wave (Hs= 0.8 m)

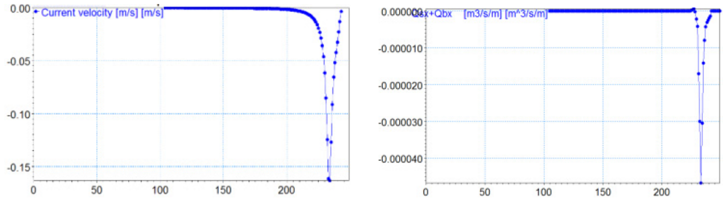

Fig.15. Longshore current (left) and sediment transport (right) crossing Profile 2 for eastern wave (Hs= 0.8 m)

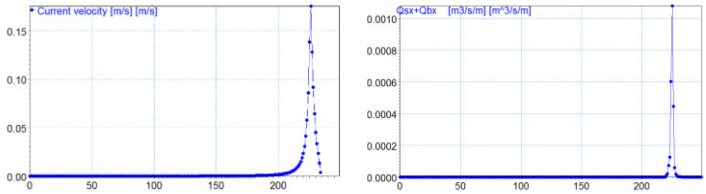

Fig.16. Longshore current (left) and sediment transport (right) crossing Profile 3 for northwestern wave (Hs= 0.8 m)

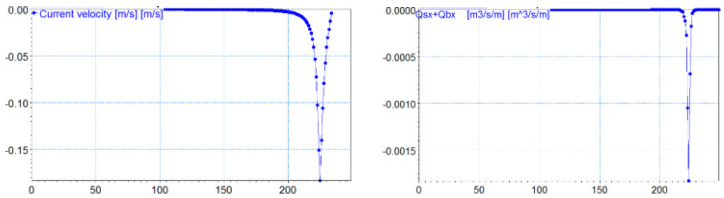

Fig.17. Longshore current (left) and sediment transport (right) crossing Profile 3 for eastern wave (Hs= 0.8 m)

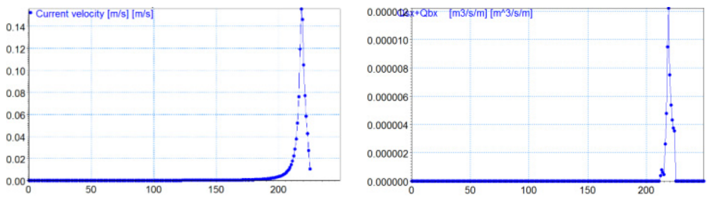

Fig.18. Longshore current (left) and sediment transport (right) crossing Profile 4 for northwestern wave (Hs= 0.8 m)

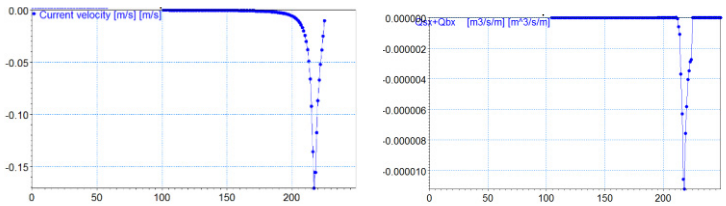

Fig.19. Longshore current (left) and sediment transport (right) crossing Profile 4 for eastern wave (Hs= 0.8 m)

ii. Accumulated sediment budget

Fig. 20 shows the accumulated sediment transport crossing Profile 1 (western groyne), Profile 2 (Sigandu), Profile 3 (Dolphin Center) and Profile 4 (Ujungnegara), from 01 January 2010 to 29 October 2013.

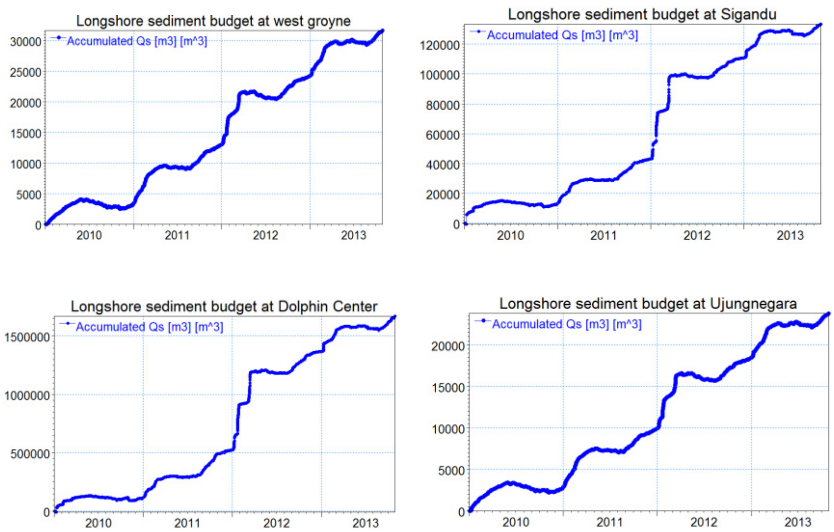

Fig.20. Longshore sediment budget from 2010 to 2013

The sediment transport calculations have been carried out for the period from 01 January 2010 to 29 October 2013, for a coastline orientation of 17 degrees (measured clockwise from the North to a line perpendicular to the beach). Table 3 presents the annual and the total littoral drift (Qs) from 2010 to 2013, and shown illustratively in Fig.21.

Table 3. Total sediment budget from 2010 to 2013[7]

Profiles	Annual net drift Qs_{net} (m^3)				Total drift (m^3) 2010-2013
	2010	2011	2012	2013	
1 (west groyne)	96767	25241	254432	27825	31662.4
2 (sigandu)	13405.1	29797.6	67712.3	22453	133368
3 (dolphin)	122110	398038	832532	298600	1651280
4 (ujungnegara)	7642.5	10712	9201.2	5899.4	25812.6

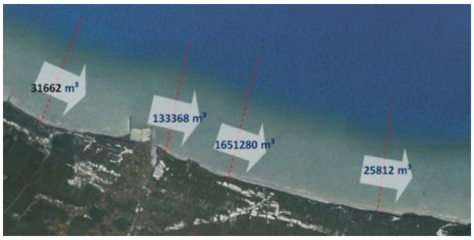

Fig.21. Total sediment budget crossing the profiles from 2010 to 2013

5. Concluding Remarks and Suggestions

a. Longshore current

- For all profiles, and for both dominant wave directions, longshore current occurs primarily within 300 m from the beach.
- For all profiles, and for both dominant wave directions, maximum longshore current velocity of about 0.2 m/s is found at about 150 m from the beach.

b. Littoral transport

- Longshore sediment drift occurs primarily within the distance of 300 m from the beach.
- Although the amount varies each year from 2010 to 2013, the net sediment budget from the west to the east is always bigger than the budget from opposite direction, and this applies to all profiles (1-4), as illustrated in Fig 21.
- The natural behaviour of Batang coastal area is that a littoral drift from the west to the east is taking place. The general trend of sediment transport in the area is that there is a net sediment transport from west to east in the early months of the year, followed by a shorter period of transport in opposite direction (westward) for a few months, then approaching end of year the net transport is back from west to east. Note that positive drift means sediment transport from west to east, while negative drift denotes the opposite.
- The fact that there has been severe erosion at segment between Profile 2 (Sabong River) and Profile 3 (east of the Dolphin Center) could be attributed to the significantly higher sediment transport leaving than entering the segment.

c. Suggestions for further study

- More cross-shore profiles are needed to obtain more detailed sediment transport along Batang coastline.
- More bathymety data farther offshore (about 8-10 km from coastline) are needed to generate regional wave model.
- More data on Sabong River discharge are needed to compute hydrodynamics and local wave modelling.

Acknowledgement

This material is based on work executed in 2013 by a team at Coastal Dynamics Research Center (BPDP-BPPT) in co-operation with the local government of Batang, Central Java. In that respect, the authors wish to thank the team members, especially those involved in the field survey for providing valuable data of the site. We would also like to thank the reviewers in BPDP-BPPT for their comments and suggestions.

References

1. Rencana Tata Ruang Wilayah Kabupaten Batang, Rencana Program Jangka Menengah Kabupaten Batang, draft RZWP3K Kab. Batang.
2. Feasibility Study, Development of Pelabuhan Niaga, Batang, 2005
3. DHI, Sediment Transport Analysis and Description of ongoing Processes – Stockton Beach case, 2006.
4. DHI, Littoral Transport and Coastal Morphology – Rodsand 2 case, 2007.
5. DHI, LITPACK - Short Introduction and Tutorial "An Integrated Modelling System for Littoral Processes and Coastline Kinetics", 2010.
6. DHI.MIKE 21 Hydrodynamics (HD) Module - User Manuals, 2010.
7. BPDP, Laporan Peninjauan Lapangan di Batang, 2013.