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Implementation of Building with Nature (BwN) as Adaptive Concept to Prevent Coastal Erosion in Demak Regency, Central Java, Indonesia

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***Abstract*—North Java, Indonesia's Shoreline degradation has become a severe problem along its coast. The gradually vanishing of the mangrove greenbelt indicates starting of coastal erosion. To overcome that problem, the adaptive concept using Building with Nature (BwN) is expected to become a part of the solution by enhancing the natural process. Construction of permeable structures was started in 2013. Its implementation was modeled using Delft3D. A coupling between Delft3DFlow and Delft3DWave is proposed. The model is conducted in two scenarios, coastal areas without and with permeable structures. Both were simulated in wet and dry seasons. It is analyzed on three years morphological scale. 10 observation points were determined in the front and back of structures. Those are utilized as control points to check the height of sediment trapped. Accumulation of sediment trapped in wet and dry seasons, and the coverage area was a dry season without structures. By adding a permeable structure, the maximum amount of sediment trapped in the wet season reaches 1.52 m in three years of simulation. It can be concluded that permeable structures constructed along the coast can trap the sediment. The placement, length, and number of structures should be considered to produce a wider coverage area. In the future, the sustainability of this adaptive concept is expected to enhance the coastal restoration in Demak coastal area.**

***Keywords*— Adaptive structure; Building with Nature (BwN); coastal erosion; Delft3D; permeable structure.**

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I. INTRODUCTION

Demak is one of the strategic regencies located in the North Java Coastal area [1]. Its location not too far from the capital city of Central Java, Semarang, Indonesia, brought many advantages, especially in economy and social development. Many people work in agriculture, trading, fishery, and aquaculture field. As a coastal region, most of the people live in the coastal area. Its coastal line is approximately 9.13 km and is famous for with productivity in fishery and aquaculture. This coastal area was very productive in agriculture for a long time ago. It is evidenced by greenbelt history lying over the coastline from 1984 to 2020. However, from the 2000's to recent years, the greenbelt gradually decreased. Its ecosystem services such as carbon sequestration, fisheries and aquaculture, wood and timber reservation, and coastal nature protection [2] become deteriorate [3].

Land cover transformation is caused by the population growth and development of the economy and society. The livelihood changes drastically from farmer to fisherman. Mangroves were substituted into ponds [4]. During the period 1985 to 2005, there are about 0,66% of mangroves in the world has lost every year [5]. It also has been observed in the last decades of 20th century that mangrove forests are degraded over one-third of the world [6]. Another research found that from 1988 to 2017, about 25% of non-water areas changed to the water area, and 5% of water areas changed to shoreline margin [7]. Eventually, people did not consider that those changes influenced the environmental condition [8]. Hence, the new perspective of building adaptive capacity concept to conquer climate change has become a crucial issue in the coastal community [9].

Recently, the degradation of mangroves' habitat as natural coastal protection induced significant erosion in Demak's shoreline. It has experienced massive coastline changes during the last decades [10]. It can be observed from Fig. 1 that in several places, the erosion is estimated to be up to 1.5 km toward the mainland.

Conversely, the significant escalation of industrial activity in coastal regions motivates the increasing groundwater extraction. Excessive groundwater extraction produces decreasing in groundwater level that leads to land subsidence [11], [12], [13]. It was observed that land subsidence occurs along the coastline in Northern Java [14]. Land subsidence in Demak and Semarang reached 8.376 cm/year and 10 cm/year, respectively [15], [16]. Land subsidence and rising sea levels are also destructive forces of water in a coastal area [17] due to climate change and anthropogenic factors that can cause ecosystem deterioration [18]. It was recorded that sea level rise in the world reached 2,8 mm/year [19]. Those two factors of climate and morphological change were predicted to prompt the coastal vulnerability in Nothern Javanesse Coastline. Additionally, tide inundation and severe shoreline degradation have increased frequently in Demak's coastal area [20].

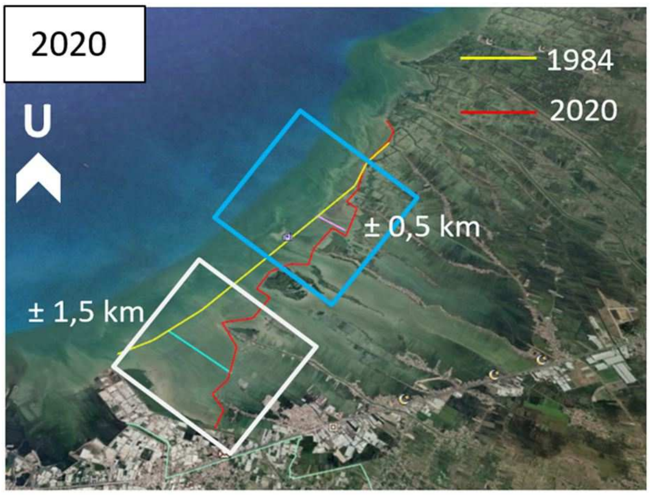

Fig. 1 Shoreline change observation from 1984 to 2020 seen from Google Earth

The necessity of coastal area development rises with the increasing coastal population and infrastructure [21]. Building with Nature is an adaptive concept that can be proposed as one of the coastal restoration methods [22]. It is considered a hybrid engineering solution that combines hard and soft solutions. By utilizing brushwood filling in the middle of bamboo piles, this method is expected to capture sediment to gain new land for mangroves to be colonized [23]. The flexibility reflects opportunities for switching between adaptation strategies and captures the diversity of potential adaptations [24]. The main idea of this concept is to enhance the natural process and ecosystem framework in terms of coastal restoration activity [25]. This method was sustainability applied and has been widely used to trap the sediment in Netherland, a line in the Mekong Delta in Vietnam [26] and a 1 km coastal line in Suriname [27], as well as to reduce erosion in Netherland [28] as seen in Fig. 2 and Fig. 3.

Fig. 2 Building with Nature concept in Suriname [27]

Fig. 3 Building with Nature concept in Netherland [28]

The pilot project of Building with Nature in Demak was conducted from 2013 to 2016 in Bogorame Village, Demak [29]. The materials were designed using bamboo and branches, as seen in Fig. 4. It made the construction method more convenient to build by community service and low-cost estimation. By using this adaptive method, additional benefit was gained for surrounding people living in Demak, such as increasing the productivity of aquaculture, as shown in Fig. 5. The environmental benefit was also promoted by mangrove restoration as an additional service in BwN concept after the sediment was trapped in the back of the structure.

Fig. 4 Sediment trapped around structure [29]

Fig. 5 Shrimps and fish live around the structure [29]

In this research, water analysis's destructive force focused on coastal erosion. Sediment trapped around structures was estimated using Deflt3D model. Moreover, coastal protection is proposed using Building with Nature concept that is adapted the permeable structure to capture sediment.

II. Materials and Method

Hydrodynamics modeling are conducted using Delft3D. Several data are used as input model, such as bathymetry, sediment, wave, and tidal data. Those data were obtained from field measurement in 2016.

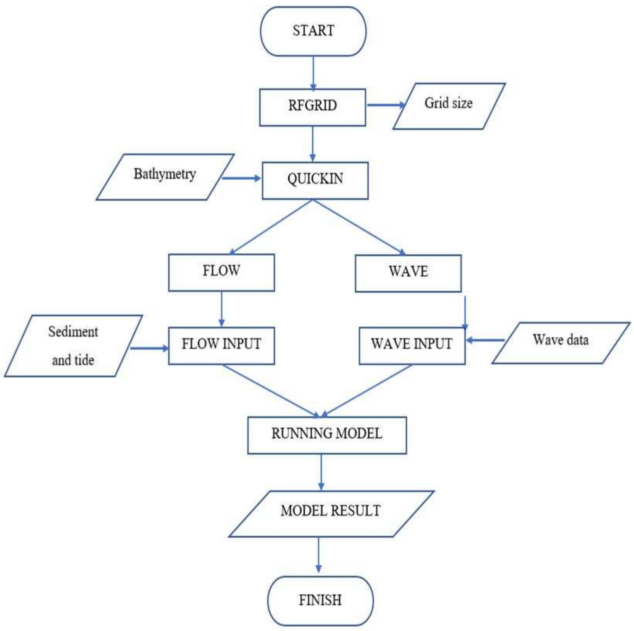

Fig. 6 Flowchart DELFT3D Modelling

Based on the analysis of sample sediment, the sediment in Demak consists of silt and clay sediment. However, it is predominantly silt. Wave data is analyzed according to a season in Demak, dry season, and wet season. In the dry season, the significant wave height is calculated at 0.253 m, the significant period is 2.596 s, and the wave direction is predominantly from North East (NE). In the wet season, the significant wave height is 0.565 m, the significant period is 3.720 s, and the wave direction is predominant from North West (NW). The tidal is observed as a diurnal type with important elevation MSL, HHWL, and LLWL are +0.01 m, +0.4 m, and -0.4 m, respectively. Using Delft3D software, permeable structures as the implementation of BwN concept are modeled. There are many functions of DELFT3D software. However, only the grid, flow, and wave models are used to conduct this simulation. Fig. 6 shows the step of modeling using DELFT3D.

A. RFGRID

To create the grid model, RFGIRD function is utilized. The model area is shown in Fig. 7, which is illustrated with a red line and covers approximately 57 km^2. The width of the model is 6.33 km, and the length is 10.5 km and 5.72 km. Furthermore, the grid is generated with a size of 35 m x 35 m.

Fig. 7 Modelling area

B. Quickin

The next step is to use QUICKIN function. The menu fills the grid with bathymetry data, then interpolates it. From Fig. 8, it is observed that the deepest elevation offshore reaches -9.2 m.

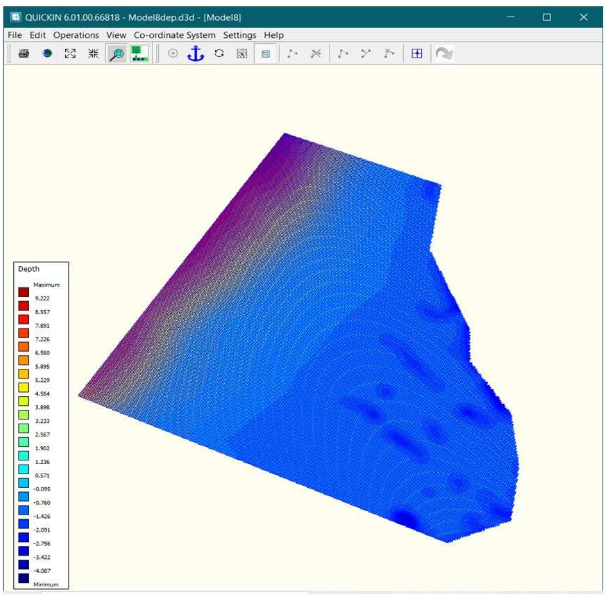

Fig. 8 The output bathymetry data from QUICKIN

C. Flow

To calculate non-steady flow and sediment transport, Delft3D-FLOW function is proposed. The simulation is considered multi-dimensional (2D or 3D) hydrodynamic. Its inputs are obtained from the tidal and meteorological forcing result on a rectilinear or a curvilinear, boundary-fitted grid. Momentum Equation was derived using Boussinesq method as well as Leibniz Equation that was used to approach hydrostatic pressure as follows:

$$\frac{\partial\xi}{\partial t}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}+\frac{\partial\{(d+\xi)U\sqrt{G_{\eta\eta}}\}}{\partial\xi}+\frac{1}{\sqrt{G_{\xi\xi}}\sqrt{G_{\eta\eta}}}+\frac{\partial\{(d+\xi)V\sqrt{G_{\eta\eta}}\}}{\partial\eta}=((d+\xi)Q) \quad (1)$$

$$\frac{1}{\rho}+\frac{\partial\rho}{\partial x}=\frac{1}{\rho_0}+\frac{\partial\rho atm}{\partial x}+g\frac{\partial\xi}{\partial x}+\frac{g}{p_0}\int_z^\xi\frac{\partial\rho}{\partial x}dz \quad (2)$$

$$\frac{1}{\rho_0\sqrt{G_{\xi\xi}}}P_\xi=\frac{g}{\sqrt{G_{\xi\xi}}}\frac{\partial u}{\partial_\xi}+g\frac{d+u}{\rho o\sqrt{G_{\xi\xi}}}\int_\sigma^0\left(\frac{\partial\rho}{\partial\xi}+\frac{\partial\rho}{\partial\sigma}+\frac{\partial\sigma}{\partial\xi}\right)d\sigma' \quad (3)$$

$$\frac{1}{\rho_0\sqrt{G_{\eta\eta}}}P_\eta=\frac{g}{\sqrt{G_{\eta\eta}}}\frac{\partial u}{\partial_\eta}+g\frac{d+u}{\rho o\sqrt{G_{\eta\eta}}}\int_\sigma^0\left(\frac{\partial\rho}{\partial\eta}+\frac{\partial\rho}{\partial\sigma}+\frac{\partial\sigma}{\partial\eta}\right)d\sigma' \quad (4)$$

Moreover, there are some data used to create a flow model:

1) Description: In the description, model scenarios are stated. This research proposes two scenarios: conditions without permeable structures and with the structures. Every simulation was conducted for two seasons, wet and dry. Wet season was determined from October to March, and from April to September is considered the dry season.

2) Domain: This menu contains grid parameters, bathymetry, dry points, and a thin dam. The Permeable Structure (PS) is defined as a thin dam, a barrier that interferes with the flow without reducing the model's total wet surface and volume. The locations of thin dams are defined from a coordinate location in Google Earth, as seen in Table 1.

TABLE I
COORDINATE LOCATIONS OF PERMEABLE STRUCTURES

No.	PS Code	UTM Coordinate		Length of PS (m)
		Latitude	Longitude	
1	6a	444422.03	9236843.24	62.7
2	7	444808.16	9237456.26	10.2
3	8	445150.44	9237124.52	9.97
4	9	445205.6	9237184.92	3.9
5	10	445251.02	9237238.56	7.96
6	11	445224.84	9237325.19	11.0
7	12c	445235.13	9237481.48	14.4
8	13	445452.87	9237942.16	8.32
9	14b	445307.69	9237967.41	25.7
10	15	445183.47	9238236.65	23.8
11	16	445245.52	9238507.38	17.9
12	17	446304.31	9240441.92	21.5
13	18	446427.21	9240667.89	16.6

3) Time Frame: The simulation time for this research is 15 days, from 1 January 2019 until 16 January 2019. This simulation time is based on the field measurement of tide data, and time step for this model is 30 s.

4) Processes: This menu is used to specify which processes or quantities that might influence the hydrodynamic simulation. In this research, the cohesive sediment parameter is used for further process. Regarding the result, silt is predominantly in sample sediment. Furthermore, the model is also coupled with the wave model in DELFT3D WAVE.

5) Boundaries: In this part, the model boundaries, the transport sediment condition, and tide are defined. The condition, time frame, and tidal data are the same as for sediment transport.

6) Physical parameters: The sediment data, such as specific density and dry bed density, are added as the physical parameters. The laboratory sample tests' values are 22380 kg/m^3 and 1330 kg/m^3 for specific and dry bed density, respectively. Moreover, a morphological scale is used to define how long the simulation was modeled. In this research, the model was calculated for three years of simulation.

7) Monitoring: To monitor the computational results, observation points, drogues or cross-sections are specified as a function of time. Those parameters can be characterized by a name and the grid indices of their locations in the model area. In this model, observation points are determined around the structures, and some of the permeable structures are constructed in short dimensions. Hence, the observation point is located around the structures' representative area. There are 10 observation points with the coordinate shown in Table II.

TABLE II
LOCATION OF OBSERVATION POINT IN THE MODEL

No.	PS Code	Observation Point	
		In Front structures	Back of Sructures
1	6a	157.173	-
2	7	-	149.174
3	8	136.151	134.151
4	9	-	-
5	10	-	-
6	11	-	-
7	12c	143.143	-
8	13	149.116	-
9	14b	-	-
10	15	144.118	-
11	16	-	138.117
12	17	134.40	-
13	18	-	131.40

D. Wave

The coupling model that was used to complete the simulation is DELFT3D WAVE. This model is utilized to simulate the evolution of wind-generated waves in coastal waters, including estuaries, tidal inlets, barrier islands with tidal flats, channels, etc. Several functions use the data that are prepared in flow model input, such as hydrodynamics input, grid, bathymetry, and time frame. The additional information that needs to be determined in boundary conditions is wave data, including significant wave height, significant wave period, and predominant wave direction, as seen in Fig. 9.

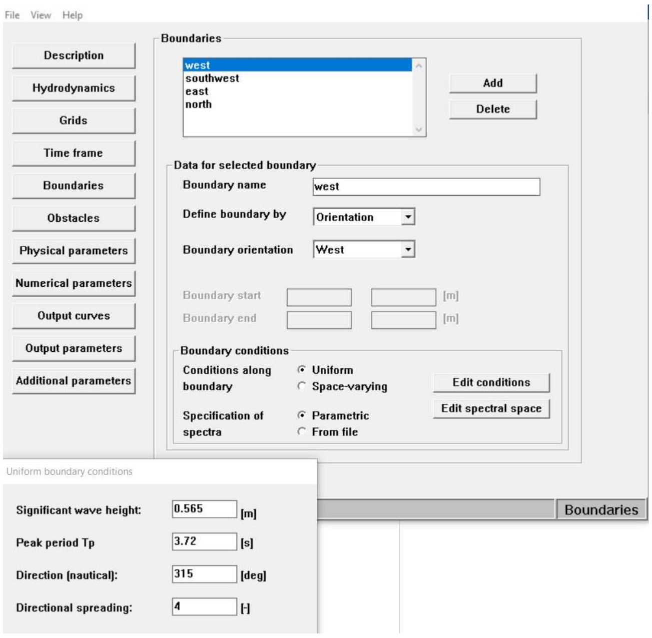

Fig. 9 Wave data input for wet season

E. Quickplot

The simulation results are visualized using Quickplot function, as seen in Fig 9(b). Illustrations of water depth for several conditions are visible for analysis. The graphs that show the height of sediment transport for certain observation points can also be produced.

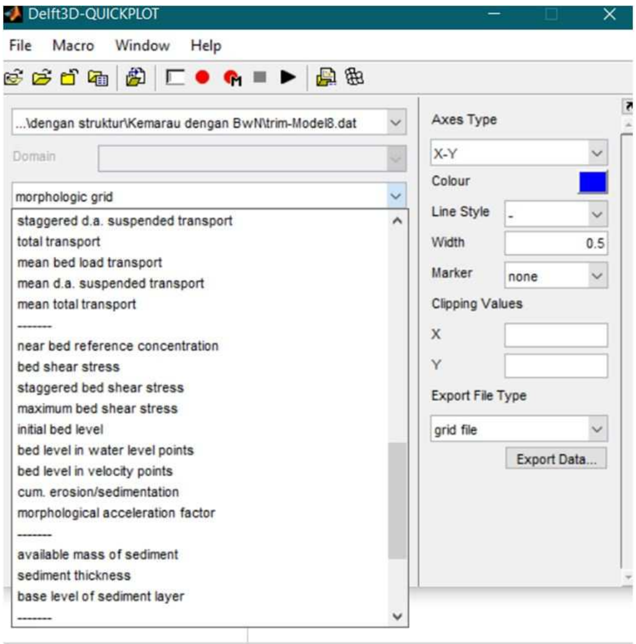

Fig. 10 The main window of QUICKPLOT

III. Results and Discussion

Hydrodynamics simulation is conducted using DELFT3D model. The model is simulated for three years in the wet and dry season. The first scenario is simulated without any permeable structures. It can be seen in Fig. 10 that in wet season, the sediments accumulate along the coastline, with a maximum depth of 1 m. However, it is observed that the sediment is rapidly washed away in the dry season. The different condition of wave height and wave energy in wet and dry seasons is one reason for this occurrence phenomenon. During the wet season, the higher significant wave height produces higher energy. Furthermore, it can induce a higher result of sediment transport in the cross-shore direction than in the dry season.

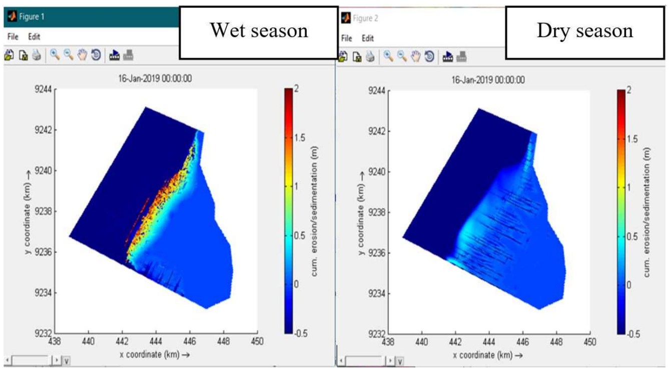

Fig. 11 Simulation result without permeable structures in wet season and dry season

The second scenario is proposed as such a real condition. The permeable structures are located along the coast [30]. The structure permeable is shown as a white line in the model. Similar to the first scenario, this model is also simulated for three years in wet and dry seasons. Based on the result, the permeable structures are able to trap sediments in the front and back of structures. The maximum sediment height is 1.52 m and the coverage area is approximately 3.5 km^2, as illustrated in Fig. 12.

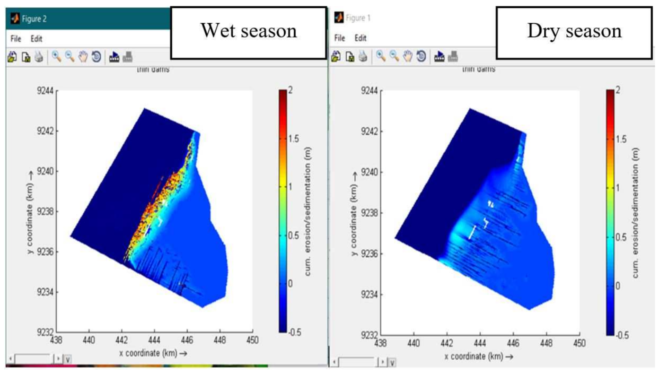

Fig. 12 Location of permeable structures in the field and simulation result with permeable structures in the wet season and dry season

The simulation result of sediment height trapped in the wet season near the structures can be seen in Table III. The sediment height around BwN6a decreases 0.15 m, from 0.9 m to 0.75 m. However, in the observation point, BwN7 and BwN13 sediment heights reach up to 1.52 m and 1.5 m, respectively (from -0.4 m to 1.12 m and from -0.6 m to 0.9 m) for three years of simulation.

Although several amounts of sediment are washed away, in the dry season, sedimentation can still be visualized in the vicinity of structures. The result of sediment trapped near the structures during the dry season is shown in Table III. It can be observed that near the BwN8, sediment trapped increases up to 0.17 m on its front side and 0.26 m on its backside. Furthermore, the example comparison condition of sediment trapped in the dry season is depicted in Fig. 13.

TABLE III
SEDIMENT TRAPPED IN WET SEASON

PS code	Length of PS (m)	Wet Season				Dry Season			
		Sediment Trap Without PS (m)		Sediment Trap With PS (m)		Sediment Trap Without PS (m)		Sediment Trap With PS (m)	
		In Front PS	Back of PS	In Front PS	Back of PS	In Front PS	Back of PS	In Front PS	Back of PS
6a	62.7	0.9	-	0.75	-	0.25	-	0.3	-
7	10.2	-	-0.4	-	1.12	-	0.25	-	0.3
8	9.97	0.27	0.2	0.3	0.3	-0.15	-0.2	0.023	0.06
9	3.9	-	-	-	-	-	-	-	-
10	7.96	-	-	-	-	-	-	-	-
11	11.0	-	-	-	-	-	-	-	-
12c	14.4	0.58	-	0.5	-	-0.15	-	0.025	-
13	8.32	-0.6	-	0.9	-	0.08	-	0.1	-
14b	25.7	-	-	-	-	-	-	-	-
15	23.8	0.1	-	0.65	-	0.1	-	0.1	-
16	17.9	-	0.45	-	0.45	-	0.05	-	0.1
17	21.5	0.6	-	0.4	-	0.01	-	0.01	-
18	16.6	-	0.4	-	0.3	-	0.4	-	0.3
	Sum	3.1		5.67		1.14		1.318	

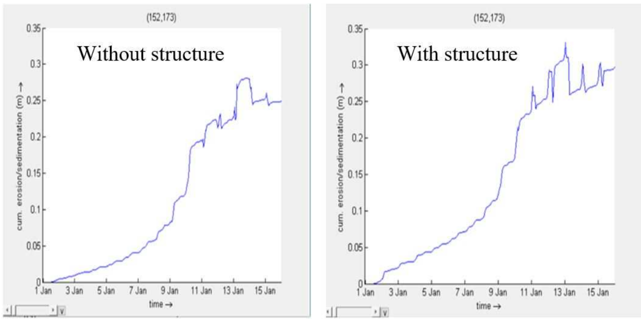

Fig. 13 The sediment trapped at observation point BwN6a in dry season for condition without permeable structures and with permeable structures

The comparison result of sediment trapped in wet and dry season around the structures is shown in Fig. 14. It can be observed that in the dry season, with and without structures, the sediment transport fluctuation is not significantly different. It shows that in dry season with structures sediment height is slightly higher than in condition without structures. Moreover, in wet season, by using permeable structures, it shows decreasing and increasing significantly, especially in the vicinity of structures BwN7 and BwN13.

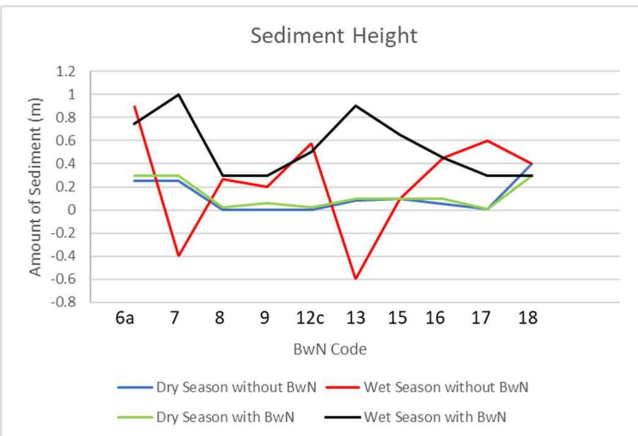

Fig. 14 Comparison of sediment height in the observation points around the structures

IV. CONCLUSIONS

The modeling of sediment trapping in Demak, Central Java, Indonesia, has been conducted by using two scenarios. First scenario is without permeable structure, second is with structures. Both are simulated in wet and dry season. Based on the result, in first scenario, more sediment is trapped along the coastal in wet season, however it is rapidly washed away during the dry season. From second scenario, the height of sediment trapping in the vicinity of structures is higher than first scenario. By constructing the structures, the maximum height of sediment trapped reaches up to 1.52 m with whole coverage area approximately 3.5 km^2. Meanwhile, in dry season, it can be observed slightly accumulation of sediment trapped around the structures. Hence, it can be concluded that permeable structures constructed along the coastal has ability to trap the sediment. By considering the placement and adding the length and numbers of structures, wider coverage area can be produced. In the future, sustainability of this adaptive concept is expected to enhance the coastal restoration in Demak coastal area.

NOMENCLATURE

u	Flow velocity in ξ-direction (x direction)	m/s
v	Fluid velocity in η-direction (y direction)	m/s
V	Fluid velocity in η-direction (y direction)	m/s
d	Depth below datum	m
ξ	Water level above datum	m
σ	Stefan-Boltzmann's constant	J/(m^{2}sK^4)
ω	Velocity in the σ-direction (σ-co-ordinate system)	m/s
ξ, η	Horizontal, curvilinear coordinates	-
$\sqrt{G_{\xi\xi}}$	Coefficient to transform from rectangular to curvilinear coordinates	m
$\sqrt{G_{\eta\eta}}$	Coefficient to transform from rectangular to curvilinear coordinates	m
ρ_0	Water's reference density	Kg/m^3
$P\xi$	Gradient hydrostatic pressure (ξ-direction)	Kg/(m^{s}s^2)
$F\xi$	Turbulent momentum flux (ξ-direction)	m/s^s

$M\xi$	Source or sink of momentum (ξ-direction)	m/s^s
$P\eta$	Gradient hydrostatic pressure (η-direction)	Kg/(m^{s}s^2)
$F\eta$	Turbulent momentum flux (η-direction)	m/s^s
$M\eta$	Source or sink of momentum (η-direction)	m/s^s

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REFERENCES

[1] M. R. Muskananfola, Supriharyono, and Febrianto SIgit, "Spatio-Temporal Analysis of Shoreline Change Along The Coast of Sayung Demak, Indonesia Using Digital Shoreline Analysisi System," *Regional Studies in Marine Science*, vol. 34, no. 101060, 2020, doi: 10.1016/j.rsma.2020.101060.

[2] C. E. J. Van Bijsterveldt *et al.*, "How to restore mangroves for greenbelt creation along eroding coasts with abandoned aquaculture ponds," *Estuarine, Coastal and Shelf Science*, vol. 235, p. 13, 2020, doi: https://doi.org/10.1016/j.ecss.2019.106576.

[3] A. Barnuevo, T. Asaeda, K. Sanjaya, Y. Kanesaka, and M. Fortes, "Drawbacks of mangrove rehabilitation schemes: Lessons learned from the large-scale mangrove plantations," *Estuarine, Coastal and Shelf Science*, vol. 198, pp. 432–437, Nov. 2017, doi: 10.1016/j.ecss.2017.02.015.

[4] A. Triyanti, M. Bavinck, J. Gupta, and M. A. Marfai, "Social capital, interactive governance and coastal protection: The effectiveness of mangrove ecosystem-based strategies in promoting inclusive development in Demak, Indonesia," *Ocean & Coastal Management*, vol. 150, pp. 3–11, Dec. 2017, doi: 10.1016/j.ocecoaman.2017.10.017.

[5] S. C. Gnansounou *et al.*, "Local uses of mangroves and perceived impacts of their degradation in Grand-Popo municipality, a hotspot of mangroves in Benin, West Africa," *Trees, Forests and People*, vol. 4, p. 100080, Jun. 2021, doi: 10.1016/j.tfp.2021.100080.

[6] D. F. Senger, D. A. Saavedra Hortua, S. Engel, M. Schnurawa, N. Moosdorf, and L. G. Gillis, "Impacts of wetland dieback on carbon dynamics: A comparison between intact and degraded mangroves," *Science of The Total Environment*, vol. 753, p. 141817, Jan. 2021, doi: 10.1016/j.scitotenv.2020.141817.

[7] R. S. Dewi and W. Bijker, "Dynamics of shoreline changes in the coastal region of Sayung, Indonesia," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 23, no. 2, pp. 181–193, Aug. 2020, doi: 10.1016/j.ejrs.2019.09.001.

[8] Y. Chen, Y. Li, C. Thompson, X. Wang, T. Cai, and Y. Chang, "Differential sediment trapping abilities of mangrove and saltmarsh vegetation in a subtropical estuary," *Geomorphology*, vol. 318, pp. 270–282, Oct. 2018, doi: 10.1016/j.geomorph.2018.06.018.

[9] J. Bush and A. Doyon, "Building urban resilience with nature-based solutions: How can urban planning contribute?," *Cities*, vol. 95, p. 102483, Dec. 2019, doi: 10.1016/j.cities.2019.102483.

[10] I. Buchori *et al.*, "Factors distinguishing the decision to migrate from the flooded and inundated community of Sayung, Demak: A suburban area of Semarang City, Indonesia," *International Journal of Disaster Risk Reduction*, vol. 52, p. 101946, Jan. 2021, doi: 10.1016/j.ijdrr.2020.101946.

[11] S. M. Khair, S. Mushtaq, K. Reardon-Smith, and J. Ostini, "Diverse drivers of unsustainable groundwater extraction behaviour operate in an unregulated water scarce region," *Journal of Environmental Management*, vol. 236, pp. 340–350, Apr. 2019, doi: 10.1016/j.jenvman.2018.12.077.

[12] H. T. Pham, W. Rühaak, V. Schuster, and I. Sass, "Fully hydro-mechanical coupled Plug-in (SUB+) in FEFLOW for analysis of land subsidence due to groundwater extraction," *SoftwareX*, vol. 9, pp. 15–19, Jan. 2019, doi: 10.1016/j.softx.2018.11.004.

[13] H. Yu, H. Gong, B. Chen, K. Liu, and M. Gao, "Analysis of the influence of groundwater on land subsidence in Beijing based on the geographical weighted regression (GWR) model," *Science of The Total Environment*, vol. 738, p. 139405, Oct. 2020, doi: 10.1016/j.scitotenv.2020.139405.

[14] L.-M. Bott, T. Schöne, J. Illigner, M. Haghshenas Haghighi, K. Gisevius, and B. Braun, "Land subsidence in Jakarta and Semarang Bay – The relationship between physical processes, risk perception, and household adaptation," *Ocean & Coastal Management*, vol. 211, p. 105775, Oct. 2021, doi: 10.1016/j.ocecoaman.2021.105775.

[15] E. Chaussard, F. Amelung, H. Abidin, and S.-H. Hong, "Sinking cities in Indonesia: ALOS PALSAR detects rapid subsidence due to groundwater and gas extraction," *Remote Sensing of Environment*, vol. 128, pp. 150–161, Jan. 2013, doi: 10.1016/j.rse.2012.10.015.

[16] P. E. Yastika, N. Shimizu, and H. Z. Abidin, "Monitoring of long-term land subsidence from 2003 to 2017 in coastal area of Semarang, Indonesia by SBAS DInSAR analyses using Envisat-ASAR, ALOS-PALSAR, and Sentinel-1A SAR data," *Advances in Space Research*, vol. 63, no. 5, pp. 1719–1736, Mar. 2019, doi: 10.1016/j.asr.2018.11.008.

[17] M. Esteban *et al.*, "Adaptation to sea level rise: Learning from present examples of land subsidence," *Ocean & Coastal Management*, vol. 189, p. 104852, May 2020, doi: 10.1016/j.ocecoaman.2019.104852.

[18] K. J. E. Walsh *et al.*, "Tropical cyclones and climate change," *Tropical Cyclone Research and Review*, vol. 8, no. 4, pp. 240–250, Dec. 2019, doi: 10.1016/j.tcrr.2020.01.004.

[19] D. S. A. Suroso and T. Firman, "The role of spatial planning in reducing exposure towards impacts of global sea level rise case study: Northern coast of Java, Indonesia," *Ocean & Coastal Management*, vol. 153, pp. 84–97, Mar. 2018, doi: 10.1016/j.ocecoaman.2017.12.007.

[20] I. Buchori, A. Pramitasari, A. Sugiri, M. Maryono, Y. Basuki, and A. W. Sejati, "Adaptation to coastal flooding and inundation: Mitigations and migration pattern in Semarang City, Indonesia," *Ocean & Coastal Management*, vol. 163, pp. 445–455, Sep. 2018, doi: 10.1016/j.ocecoaman.2018.07.017.

[21] I. Buchori *et al.*, "A predictive model to assess spatial planning in addressing hydro-meteorological hazards: A case study of Semarang City, Indonesia," *International Journal of Disaster Risk Reduction*, vol. 27, pp. 415–426, Mar. 2018, doi: 10.1016/j.ijdrr.2017.11.003.

[22] H. de Vriend, M. van Koningsveld, and S. Aarninkhof, "Building with nature': the new Dutch approach to coastal and river works," *Proceedings of the Institution of Civil Engineers - Civil Engineering*, vol. 167, no. 1, pp. 18–24, Feb. 2014, doi: 10.1680/cien.13.00003.

[23] T. Wilms, B. K. Van Wesenbeeck, and F. H. Tonneijck, "Technical-Guidelines-Permeable-Structures_Building-with-Nature-Indonesia.pdf," Ecoshape, 2020.

[24] J. E. Cinner, W. N. Adger, E. H. Allison, and M. L. Barnes, "Building adaptive capacity to climate change in tropical coastal communities," *Nature Climate Change*, vol. 8, p. 8, 2018, doi: DOI:10.1038/s41558-017-0065-x.

[25] K. McDonough, S. Hutchinson, T. Moore, and J. M. S. Hutchinson, "Analysis of publication trends in ecosystem services research," *Ecosystem Services*, vol. 25, pp. 82–88, Jun. 2017, doi: 10.1016/j.ecoser.2017.03.022.

[26] B. K. Veettil, R. D. Ward, N. X. Quang, N. T. T. Trang, and T. H. Giang, "Mangroves of Vietnam: Historical development, current state of research and future threats," *Estuarine, Coastal and Shelf Science*, vol. 218, pp. 212–236, Mar. 2019, doi: 10.1016/j.ecss.2018.12.021.

[27] I. S. Tas, "Mangrove Project Suriname," Delft University of Technology, 2018.

[28] H. J. de Vriend, M. van Koningsveld, S. G. J. Aarninkhof, M. B. de Vries, and M. J. Baptist, "Sustainable hydraulic engineering through building with nature," *Journal of Hydro-environment Research*, vol. 9, no. 2, pp. 159–171, Jun. 2015, doi: 10.1016/j.jher.2014.06.004.

[29] T. Wilms, F. V. der Goot, and A. O. Debrot, "Building with Nature - an Integrated Approach for Coastal Zone Solutions Using Natural, Socio-Economic and Institutional Processes," presented at the Coast and Ports Conference, Cairns, Jun. 2017.

[30] I. S. Bumi, Widyaningtias, and M. B. Adityawan, "Coastal Erosion Management by Implementing Concept of Building with Nature (BwN) in Demak Regency, Central Java, Indonesia," *IOP Conf. Ser.: Earth Environ. Sci.*, vol. 698, no. 1, p. 012005, Mar. 2021, doi: 10.1088/1755-1315/698/1/012005.