Article

Loading Criteria and Deposit Layer Characteristics as Causes of Sediment Settlement in an Estuary

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Abstract: Sediment compaction due to the extraction of groundwater and self-weight consolidation, and monitoring land settlement of the river delta using geodetic measurement has been executed in several studies, while sediment settlement in the estuary is hypothesized due to dynamic loads. The present study aimed to observe clues for the occurrence of sediment settlement due to loading variation and deposit layer characteristics in the estuary. This research was based on four loading data for examination, i.e., hydraulic head pressure, sediment transport rate, sediment deposition, and water density. Two years of previous research simulations, including the rainy and dry seasons, were recalculated to gain the load pressure and were considered to assess the maximum load prediction. This review found evidence that dynamic loads predominated in maximum pressure changes in boreholes (BH2) and (BH3), and were due to river discharge and tidal occurrence, respectively. The dynamic load of sediment in BH2 contributed more than in BH3, where it was almost nonexistent. Observing the sediment layer characteristics, both settled for almost a month and two weeks, respectively, showed sediment settlement of more or less than 2 and 8 mm. Despite insignificant loading changes, these findings can further our understanding of loading criteria and settlement in different geometric locations.

Keywords: sediment loading criteria; sediment layer characteristic; sediment settlement

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1. Introduction

Sediment settlement in a river delta is commonly mentioned as increasing the risk of flooding due to the loss of deltaic land [1,2]. On the other hand, the appearance of deltaic land in the estuary environment is defined by the dominant influence of sediment supply that is neither transported from river flow nor from tides [3]. Before the transported sediment produces the river delta, siltation is first formed, which also has another consequence. It might obstruct fishers through the estuary pathway leading to fishing in the sea [4]. Both of these points of view describe that settlement occurs because of the consolidated sediment.

This study examined settlement in shallow estuaries with an additional load in the water column; in comparison, our previous research focused on self-weight consolidation [2,5,6]. The shallow estuary is deposited with sediment, which reduces the volume of the channel geometry. The load in the water column means that the river flow and tides

act as a hydrodynamic load to consolidate the deposited sediment. Sediment deposition is invariably loaded every time, either away from water level changes due to the tides or by the height variations due to river discharge in the dry and rainy season [7]. Both are called hydraulic head fluctuation, which adjusts water pressure changes and are the reason why the bed surface sediment is gradually lowered [8]. Moreover, the water density loading and sediment transport rate in the water column are also considered contributing factors. Becker and Sultan [9] denoted that the settlement would continue and compact the sediment through time.

Several theories on the origin of land settlement accompanying compaction have been proposed. Settlement due to groundwater extraction for beach [10], domestic, and agriculture [11] infrastructure has been evaluated by monitoring geodetic measurements. Compaction due to hydrodynamics has been analyzed in the coastal area to predict settlement using numerical models [12,13]. The numerical model supported the development of Monte Carlo stochastic simulations and adopted hundreds of samples to simulate Holocene sediments in the river deltas [14]. Furthermore, soil consolidation theory began to be employed based on the total settlement of sediment compaction [1,15]. The total settlement has evolved with the use of geographic information system (GIS) analysis until recently [11–14]. The settlement stated by [2] considered the settlement only from gravity-driven self-weight, whereas [6] demonstrated that the new deposition maintained self-weight pressure.

A primary concern of the sediment settlement in this study is the repercussions of the loading variation during seasonal changes and deposit layer characteristics. There was no discussion about the loading characteristics in the estuary water column, including sediment transport, sediment deposition, water density, and hydraulic head.

2. Materials and Methods

2.1. Site Locations

In selecting the study location, the sediment process, geomorphology, and lithology sediment needed to be considered. The geological map in Figure 1 shows the downstream reach of the Bengawan Solo River. It also depicts the alluvium sedimentology in the surrounding river area. The alluvium sedimentology (yellow—plain) means the sediment material that would be transported along the river is only cobbles, pebbles, sand, clays, and local shell fragments. It could also be sourced from upstream, which does not appear on the map. However, based on the mechanism of the transported sediment, the coarse sediment soil would deposit first before entry into the estuary, then it would continue depositing fine sediment soil steadily up to the estuary.

Furthermore, another view of the sediment process was based on seasonal changes. This would affect the variations of lithology sediment (stratigraphy unit). As a fisher stated, the deposited sediment changes following the seasonal changes. The sand materials would mostly be deposited in the rainy season, and mud would be deposited in the dry season. The geomorphology on the river branch, indicated in Figure 2 (Junction A and B), shows that the characteristics of the deposited sediment would be more varied between sand and mud material. This is due to the situation of the river embankment morphology, which is perpendicular to flow from upstream and could be eroded higher and affected by the amount of sediment transport. Therefore, choosing BH2 and BH3 as borehole site locations allowed us to show the differences of stratigraphic units more clearly before and after the river branch.

Figure 1. Geological map depicting the age of sediments. Site of borehole (BH) locations (BH1 was studied by Soemitro et al. (2020); BH2 and BH3 were studied by the authors with a different sampling method; BH4 followed the same sampling method as that for BH1). B4 was investigated to observe the sediment transport rate and involved BH3 due to its presence on the same channel (uniform flow).

2.2. Loading Data

Field observation and several methods followed those of the previous research in Bengawan Solo River Estuary at BH2 and BH3, Figure 1 [16]. The BH stands for borehole, which is the location for sampling sediment and load parameters. There were four kinds of load parameters for the consolidated sediment, i.e., hydraulic head pressure, sediment transport rate, sediment deposition, and water density.

Figure 2. Column sampling of material on the river span.

The load parameter was obtained from observation and modeling and combined to determine the pressure load combination. Furthermore, the rainy and dry seasons were compared to determine which season experienced the maximum pressure load. Selecting contrasting geometry at the locations was used to compare and review the sediment settlement behavior, which was because of the hypothesis that at the end of the pressure load evaluation the load would be different at BH2 and BH3.

2.2.1. Hydraulic Head Pressure

The hydraulic head of the level unit (m) was re-examined by including the density of water to achieve the hydraulic head of the pressure unit (kPa). It was analyzed via the HEC–RAS (Hydrologic Engineering Center–River Analysis System) software using one-dimensional unsteady flow result simulations [17]. The boundary conditions upstream and downstream were river discharge and tides. The tidal range of the higher and the lower water level was 1.41 m. It was based on field measurement data from 6–20 November 2018 at BH1, used to validate the result simulations, with root mean square error (RMSE) of 0.9 (Figure 3). There was no wave parameter in the boundary area simulation due to wave breaking on the delta before entering the estuary. The bed roughness parameter of the river was set at 0.025. The river has situation characteristics with no vegetation on the main and levee channels, based on Manning’s value. The simulations were considered for two years before and after the Sembayat Weir was constructed. The time-step for the detailed output interval was set at one hour. The pressure was considered based on the difference of water level changes shown in Figure 4. When the present water level was lower than that of the following period, it indicated a load addition. On the contrary, there was no load reduction if the following period was lower than the current water level.

Commonly, a water level that becomes lower indicates that the hydrostatic pressure also decreases. However, the behavior of continuously flowing water, always bringing and eroding sediment, was assumed as producing a constant load. This was due to the erosion process being considered as supplying axial and lateral force to the riverbed.

Figure 3. Validation of the simulation results at BH1 (red and blue line represent field measurement and simulation data, respectively).

Figure 4. Loading scheme of hydraulic head pressure and continuous flow.

2.2.2. Sediment Transport Rate

HEC-RAS did not simulate the sediment transport rate because it does not support the suspended sediment concentration (SSC) as an input parameter. Another method has been conducted by [18] using an artificial neural network (ANN) to understand the behavior of SSC in the estuary. However, this study carried out a simplified method for assessing the transport rate by taking sample material for each month and processing it into a power equation formula to predict SSC during the same period with the hydraulic head parameter. There was no measurement of turbidity. The sediment transport rate was controlled by the outflow discharge and the tidal pumping. This specific data observation is not yet published, and the sampling material follows the previous study [16].

2.2.3. Sediment Deposition

Determining sediment deposition depends on the sediment transport rate that runs in or out along the flow course conducted by point controlling at B4. Based on the principle of the continuity equation, the discharge of a steady flow is uniform along the channel [19]. Therefore, the amount of sediment transport in suspension was controlled in the BH3–B4 river segment area with a distance of 550 m (Figure 2). Handling was also included in the flow velocity. They were measured within four water columns for each cross-section and consisted of a three-point observation in any depth (h) of the water column (0.2, 0.6, and 0.8 h) to observe the spread of material. The suspended sediment and flow velocity were taken using a bottle water sampler and an electromagnetic current meter (Marsh Mc Birney Model 21 series; manufactured by Hach Company, Loveland, CO, USA). The limitation of this observation was that sampling took place at different times, and the column (point) sampling was also changed (Figure 2). Therefore, the cross-section of each month's sampling location constantly changed because fishers did not permit the installation of stakes on the riverway, which otherwise may have been measured precisely. This was carried out via moving the water column from site to site to obtain a cross-section

from upstream to downstream by fisher boat. The time gap was two hours adjacent to the cross-section. This approach made it possible to represent the sampling material simultaneously as consideration of flow velocity was still relatively constant. It was also supported by the diurnal tides when the data collection was conducted at noon.

2.2.4. Water Density

The density of water occurring in the estuary consists of freshwater ρ_w and seawater ρ . Determining the water content of seawater or freshwater was conducted using a water quality tester (Constant WT61, manufactured by Constant Instruments, Joondalup, Australia). It was tested after sampling suspended sediment by a bottle sampler on the boat. Figure 5 illustrates the salinity contour data processed in SURFER 2D software on the cross-section of BH2. The salinity was well mixed except during July 2017. It could be possible due to the transition from ebb to flood or contrariwise, following the water sampling. This exchange phenomenon representing the tidal condition was stratified flow. The salinity results shown in Table 1 are the average data for the 0.8 depth (h) of each water column. Choosing 0.8 h was due to the higher turbidity or sediment concentration attainable close to the riverbed.

Table 1. Data measurement of water physics in the Bengawan Solo River estuary.

	BH2			BH3		
Sampling Time	ρ (kg/m ³)	Salinity (ppt)	Temperature (°C)	ρ (kg/m ³)	Salinity (ppt)	Temperature (°C)
October 2016	996.09	0.13	28.84	996.11	0.23	29.05
November 2016	996.57	0.50	28.17	996.57	0.51	28.18
December 2016	996.14	0.14	28.72	995.98	0.15	29.28
January 2017	996.03	0.19	29.22	995.46	0.20	31.10
February 2017	996.21	0.21	28.62	996.28	0.20	28.40
March 2017	995.79	0.28	30.22	995.96	0.27	29.65
April 2017	996.23	0.17	28.48	996.08	0.16	28.95
May 2017	996.18	0.80	30.22	1001.84	8.54	30.53
June 2017	996.51	0.63	28.68	1000.71	6.36	28.95
July 2017	1001.77	7.70	28.74	1001.42	7.40	29.15
August 2017	1002.46	8.47	28.36	1002.64	8.91	28.85
September 2017	1002.49	8.90	29.30	1002.21	8.95	30.33

The water density is calculated based on equation states [20] from data on temperature t and salinity S . The equation for ρ was obtained from the calculation of the density of freshwater ρ_w (salinity = 0) as follows:

$$\rho_w = 999.842594 + 6.793952 \times 10^{-2}t - 9.095290 \times 10^{-3}t^2 + 1.001685 \times 10^{-4}t^3 - 1.120083 \times 10^{-6}t^4 + 6.536332 \times 10^{-9}t^5 \quad (1)$$

Seawater ρ was then calculated as follows:

$$\rho(S, t, 0) = \rho_w + S(0.824493 - 4.0899 \times 10^{-3}t + 7.6438 \times 10^{-5}t^2 - 8.2467 \times 10^{-7}t^3 + 5.3875 \times 10^{-9}t^4) + S^{3/2}(-5.72466 \times 10^{-3} + 1.0227 \times 10^{-6}t^2) + 4.8314 \times 10^{-4}S^2 \quad (2)$$

Figure 5. The cross-section of salinity contour data at BH2.

2.3. Observation Methods

The consolidated sediment is the preserved fluvial deposit subsequently burdened by the load on it (water column). The fluvial deposit (sedimentology) had various sediment lithology, which depended on the types of transported and settled sediment at that moment [21]. As claimed by the fishers, the fluvial deposits transform consistently with seasonal changes. In engineering practice, lithologic characteristics of fluvial soil deposits

are divided into sand, silt, and clay [6]. Determination of sediment lithology used for grain-size analysis followed the American Society for Testing and Materials (ASTM) D6913 standard. In this study, silt and clay were categorized as a soft sediment layer.

Regarding the sediment consolidation phenomenon, an oedometer test was authorized as appropriate for the one-dimensional Terzaghi's consolidation model [22]. We had no consolidation model to validate the settlement in the field. In observational studies, the sediment depositions at BH2 and BH3 were drilled until −5 m from the bed surface. The selection of BH2 and BH3 was due to considering the geomorphological process (erosion–transport–deposit) [23] that was triggered at the river branch and affected the sediment transport rate among junctions A and B. Furthermore, the drilled depositions of −5 m were assumed since the thickness could already represent lithologic data. The lithology of the depositional environment in the upper and lower delta plain (subaerial delta) [3] consists of silty sand and clayey silt [2]. It was determined by using a thin-walled tube sampler appropriate for the ASTM D1587 procedure and observed in the Laboratory of Soil Mechanics and Rocks (ITS Surabaya). The consolidation test was based on ASTM D4235-04 and set up 2 cm high and with a 6.5 cm diameter in saturated conditions. The loading increment in the laboratory was unlike the field loading behavior. However, the void ratio changes and compressibility coefficient were used for calculating the final settlement, S , using the equation below [24]:

$$S = S_1 + S_2 + S_3 + \dots + S_n = \sum_{i=1}^n S_i \quad (3)$$

$$S_i = \frac{\alpha_i \times \Delta p_i \times h_i}{(1 + e_{0i})} \quad (4)$$

where S_i is the compaction for each layer in mm, i is the total number of stratigraphic layers, α_i is the compressibility coefficient of each layer in MPa^{-1} , Δp_i is the pressure from the total number of loading data, h_i is the thickness of each layer in m, and e_{0i} and e_i are the initial and final void ratio of the laboratory test.

To identify the time duration from initial to final settlement, this study only used primary consolidation and the time corresponding to the particulars of consolidation using t_{100} (100% consolidation). The criteria for selecting the time factor T_v against the degree of consolidation $U\%$ follow [22]:

$$T_v = \frac{\pi}{4} \left(\frac{U\%}{100} \right)^2 \quad (5)$$

$$C_v = \frac{T_v H_d^2}{t_{50}} \quad (6)$$

where H_d is the length of the drainage path, which is half the specimen height at the appropriate increment or double-sided drainage.

3. Results

3.1. Characteristics of Sediment Transport Load

The suspended sediment concentration (SSC) was evaluated as a feature of sediment transport load and correlated against flow velocity, as shown in Figure 6a,b. It is the plot of instantaneous profiles. Please note that there are no data for observations of water flow direction or particle size distribution of sediment transport. The performance results of flow velocity during the rainy seasons (October 2016–April 2017) did not show a uniform sediment transport rate. The results, as shown for November, February, and April, indicate the maximum velocity conditions at BH2. However, the amount of sediment transport in February was a one-third smaller than in November and April. In February, rhythm inequivalent was possible because the gate operating system at Sembayat Weir closed the gate. Overall, the discharge was not significant, i.e., 578 m^3/s in November, 613 m^3/s in February, and 617 m^3/s in April (Figure 7).

Figure 6. Correlation between SSC and flow velocity at BH2 (a) and BH3 (b).

Ji et al. [25] proved that some types of sediment transport were simulated based on the flood hydrograph at Nakdong River Estuary Barrage. Observing BH3, the sediment transport rate also varied during the rainy season. In November, the expressive tendency of the sediment transport rates was caused by vulnerable erosion at the river branch and supported by the high flow velocity, except on column 1. It was located beyond the inner bend of the river, which slightly curved when observed spatially. In contrast, the slower flow velocity in the dry season (May–September 2017) showed a higher sediment transport rate in July–September at BH2. Two months of sediment transport, in May and June, were smaller because the saline content at the location had not intruded at that time when sampling (Table 1).

Figure 7. Sediment transport rate and flow discharge relation.

Furthermore, BH3 produced a sediment transport rate throughout the dry season. A more simplified characteristic of the sediment transport rate is displayed in Figure 8. These results suggest that BH3 received more sediment transport load in the rainy season. Narrowing and shallowing of channel geometry at BH3 could also be a reason for increased bottom shear stress due to current flow and resulted in a higher sediment transport rate. On the other hand, the flood current in the rainy season was a powerful contributor to flushing the deposited sediment when the Sembayat Weir opened (Figure 1) within the area. This would reduce the sediment transport rate at BH2 and BH3 if the gate closed during the dry season. Nonetheless, the tidal current has a role in eroding the sediments around BH3 [18].

3.2. Sediment Deposition Correlation

The maximum sediment transport load at BH2 and BH3 in the rainy season was around 2–2.5 kg/m³ in November 2016 and April 2017, while during the dry season, August–September 2017, it was 1 kg/m³. Figure 9 compares sediment transport load (in the form of suspended sediment concentration) and flow velocity from BH3 to B4 in the dry season. Both segments were considered to have similar physical and kinematical characteristics, proven by the discharge similarity (Figure 7). The dry season was chosen since quiet water frequencies in the tidal regime occurred often. The quiet water occurred due to the switchover in the transition from ebb to flood or vice versa. The concept of mud sedimentation in the estuary, including flocculation, hindered permeability, and effective stress was divided based on mass concentration: suspended, fluid mud, recently deposited, and settled [26]. Hence, this study assumed that suspended sediment would settle and deposit in the case of the submerged weight of the sediment grain or flocculation being larger than the drag force. Furthermore, the flow velocity distribution at the bottom (friction velocity) would erode the bed sediment material along the BH3–B4 segment area, which is beyond the area of quiet water.

Figure 8. Comparison of sediment transport rates at BH2 and BH3 in one year of sampling sediment.

Quantitatively, the results denote the SSC among the inflow and outflow in June and August 2017, demonstrating the sediment equilibrium on erosion and deposition. This result justifies the argument of complexity, taking into account sediment deposit accumulation [6]. Therefore, the variation in the ground level changes is not discussed because the method does not work effectively to determine sediment deposition accuracy.

Figure 9. Sediment transport load and flow velocity in the BH3–B4 segment area.

3.3. Fresh and Saline Water

As shown in Table 1, the fresh and saline water prove the water density according to the specific formulation stated in Section 2.2.4. There was no significant change in the results of measurement between 996 and 1002.5 kg/m³ of data. Likewise, the water temperature was in the range of 28.17°–31.10°. The low salinity levels, which vary between 0.1 and 0.8 ppt at BH2 and BH3, were influenced by the rainy seasons (October 2016–April 2017) because of continuous flowing river discharge; thus, the seawater could not counter the river flow. In comparison, high salinity, between 6–9 ppt, occurred in the dry season

between May 2017 and September 2017. However, there was a two-sample discrepancy in salinity of the water in May and June at BH3. This was due to the time of water sampling. The seawater condition began to enter the river channel, and the saline water had not reached BH2. The presence of saline water indicated it was still flowing at BH3. It is even possible that the opposite phenomenon could occur: the water started to flow from BH2 to BH3. Based on the field observation, it is necessary to know that the receding of seawater is faster than the entrance of seawater to the river when Sembayat Weir is closed.

3.4. Pressure Load Combination

Observing Figure 10, the maximum sediment transport rate contributed approximately $0.38\text{--}0.62\text{ kg/m}^3$ and $0.15\text{--}0.27\text{ kg/m}^3$ at BH2 and BH3, respectively. Furthermore, the water density was only taken into account in the dry season because the salinity was higher and supplied more pressure (Table 1). The next loading result of the survey was concerned with the water level changes for each water column situation on the BH2 and BH3 cross-section (Figure 11). Based on the criteria, variation in the depth of the water presented a load of each water column that was also different. Therefore, the sediment settlement was represented in 1 m^2 of the bed surface area in the middle of the river section and adjusted to the borehole site location.

Figure 10. Loading condition by hydraulic head (left y-axis) and sediment transport rate (right y-axis) at BH2 (a) and BH3 (b).

Figure 11. Cross-section of BH2 and BH3 with variations of the water depth on each column.

In consolidation theory, the sediment had undergone an overburden of pressure through time. Referring to Section 2.2.1, overburden pressure is assumed in the process of water level fluctuation that has not yet appeared, and the present maximum pressure displayed in Figure 10a,b may have occurred in the past. The maximum hydraulic head pressure of BH2 was 42.77 kPa in the prior rainy season before Sembayat Weir was constructed; while BH3 was 31.81 kPa which occurred in the transition of dry to rainy season after Sembayat Weir was constructed. Owing to a lack of historical data, the hydrostatic pressure condition applying to the tidal-dominant water region had significant water level changes during the dry season, resulting in the changes for SSC becoming higher. Therefore, a load occurs at that moment. High load pressure at BH2 was influenced by channel geometry, becoming narrow at the river branch, and the Sembayat Weir did not exist at that time. Therefore, there was a flux flow, while the flood or ebb tide caused the water level to become higher. Considering BH3, a high-pressure load took place after the weir was built, and the last simulation was higher than the previous one.

3.5. Sediment Layer

The sediment grain distribution, shown in Figure 12, compared the layer characteristics of the Bengawan Solo River estuary. There are five and fifteen layers of silt and clay in the consolidation model at BH2 and BH3, respectively. The sand was considered settling immediately due to the porous material. This was a different method of taking the sample material. Analysis of BH1, conducted by Soemitro et al. [27], used the same method as applied to BH4, i.e., the sampling sediments were taken at the depths of 1, 3, and 5 m. This method did not detail sediment parameters to review the settlement behavior on the shallow drill core (five meters). Furthermore, BH1 and BH2 showed significant sediment grain distribution at the −2 to −3 layer with a distance of only 2.5 km, invariable in river span. The expression was probably caused by the high performance of the hydrodynamic conditions at BH2 related to the close proximity to the river morphology (branch geometry).

Figure 12. Stratigraphy of sediment grain distribution.

4. Discussion

An initial objective of this research was to identify clues to the occurrence of sediment settlement. This study found that various loading types did not contribute much to settling of the sediment bed surface. It showed a discrepancy in the occurrence of the hypothesized condition in the estuary. An observation against sediment layer characteristics that were studied in the river delta (Figure 13a) was compared to sediment under loading water in this research (Figure 13b). The findings confirmed the total time of primary consolidation, and the dots in both graphs denote a 100% degree of consolidation. BH2 and BH3 settled for almost a month and two weeks, respectively, for settlements of more or less than 2 and 8 mm. This indicated that the sediment deposit underwater settled rapidly, but settlement was small.

In comparison to the river delta, Zhang et al. [2] estimated 37 years for 23 cm sediment settlement, while Liu et al. [6] estimated 18 years for 48 cm. This shows the significance gap. Indeed, the thickness of soft layers was 1.57 and 3.68 m for BH2 and BH3, and 9 and 10 m for Zhang et al. [2] and Liu et al. [6], respectively. By adopting BH2 and BH3, the differences in sediment distribution characteristics for accumulating the compaction can be understood, as shown in Figure 14. The sediment characteristics affecting the settlement at BH2 were because the sand distribution was greater than that of soft soils. The void ratio and compressibility coefficient of each layer also affected the settlement time. The void ratio at BH2 was an average of 1, meaning the material was more sand dominant than that of BH3. However, the compressibility test was not proven for the sand layer due to the nonplasticity of the materials to compare the results. Moreover, the hydrodynamic load behavior in deeper water (BH2) also had a higher lateral flow force than in shallow-water conditions in BH3. This is based on Bernoulli's energy equation principle and is accurate for tides in the estuary, which has a slope of bed sediment toward the shallower river mouth. However, an evaluation of the lateral flow force was not considered quantitatively.

in this study, especially the load due to erosion processes that might also be able to produce an axial load influencing the settlement sediment.

Figure 13. Comparison of sediment settlement in the previous study on the river delta by Y. Zhang, et al. (2018) and Y. Liu, et al. (2019) (a) and present study at BH2 and BH3 (b).

Figure 14. Sediment consolidation parameters consisting of clay content (%), void ratio, and compressibility coefficient (α) at BH2 and BH3.

5. Conclusions

This study identified different geometric conditions considering the high loading pressure. BH2 was subjected to higher load pressure in the deeper water than BH3, which was lower. Loading criteria at BH2 proved that the water level became higher due to channel geometry changes, becoming narrow and branching off, and larger river discharge. While BH3 was predicted, there was no additional load because of the maximum pressure of flood tide reoccurring in the last simulation. It may be possible that the previous period data at BH2 had a higher load pressure. Therefore, it would be possible for future research and should be supported by historical data. Sediment layer characteristics in both locations were reviewed against a loading column settled for almost a month and two weeks, respectively, for sediment settlements of more or less than 2 and 8 mm at adjacent times, i.e., five years for a 10 cm settlement, but distinct processes. BH2 was predicted due to the sand distribution being greater than that of soft soils. Likewise, the opposite condition occurred in BH3. The void ratio and compressibility coefficient (α) also affected the settlement time. However, there was no comparison between these parameters because of the nonplastic material in BH2. The findings reported in this paper can further our understanding of the loading criteria and settlement characteristics of the estuary area.

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