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Original Article

The Regulate Section Channel Model for Maintenance Channel in Estuary

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Abstract - *River estuaries hold an important role apart from being a channel for channeling floods to the sea, as well as a channel for water transportation. Silting, narrowing, moving and closing of the channel due to sedimentation have become serious problems generally occurring in estuaries. Handling so far has been handled by the construction of jetty, dredging, building underwater sills and fluidization. These methods do not seem to be the right solution in certain conditions, especially regarding costs and environmental impacts. The sistem of the Arrangement Section Channel Model, which, with its velocity, can flush sediment, is an alternative solution to the problem above. Parameters that influence this research are cross-sectional parameters, flow parameters and sediment parameters formulated in the equation* $Qs = f\ (b, b^*, h^*, h, u, t, Q, g, \rho w, \mu, \rho s)$. *Where* Qs *is the flushed sediment discharge,* b *is the width of the river,* $b*$ *is the width of the flushing section,* h^* *is the height of the flushing section, "h" is the water level,* u *is the flow velocity,* t *is the tidal period,* Q *is river discharge,* g *is gravity,* w *is water mass density, is fluid viscosity and s is sediment mass density. The research used was experimental at the River Laboratory of Civil Engineering, Faculty of Engineering, Hasanuddin University. The research results show that the greater the composite cross-sectional width ratio value, the greater the Reynolds number, and the critical shear stress causes flushing sediment discharge, which is greater than the composite cross-sectional height ratio, which is larger and causes flushing sediment discharge to decrease. The flushing pattern occurs when sediment deposition occurs in the upper reaches of the river and scours downstream in the estuary mouth area, where the amount of deposited and eroded material increases as the percentage of the composite cross-section is large but setting the cross-section with a percentage that is too large, seems to change the scour deposition to the upstream area. The Meyer Peter Muller (MPM) equation is closer to this research.*

Keywords - *Flushing, Sediment, Regulate, Section, Estuary.*

1. Introduction

River estuaries hold an important role; in addition to being a channel for canalization of floods to the sea, they are also a channel for water transportation, shipping of ships going in and out of ports located on rivers, as well as transportation connecting inland areas with cities located on estuaries or on the coast.

In order for the river channel to provide continuous service, the dimensions of the channel need to be maintained regularly, especially in areas with high sedimentation rates. Silting, narrowing, moving and closing of the channel due to sedimentation have become serious problems generally occurring in estuaries.

So far, the silting and narrowing of the channel due to sedimentation have been overcome by training jetty buildings dredging as stipulated by the Minister of Transportation of the Republic of Indonesia number 125 of 2018 concerning Dredging and Reclamation and underwater sill buildings. These methods do not seem to be the right solution in certain conditions, especially regarding costs and environmental impacts.

The occurrence of erosion/abrasion and accretion on the outside of the jetty, the relatively high cost of dredging (especially if the volume being dredged is relatively small), and the limited suitable beach geometric conditions are the drawbacks of the several methods mentioned above.

(M. Thaha, 2006) researched the Fluidization System for Channel Maintenance Engineering, [1] researched coastal navigation inlets, [2] examined the effect of cross-sectional shape on sediment deposition at the bottom of the channel (Schindfessel et al., 2015) investigated the effect of cross-sectional shape on flow patterns in open channel branching, [4] researched an integrated method for optimal cross-section dredging design.

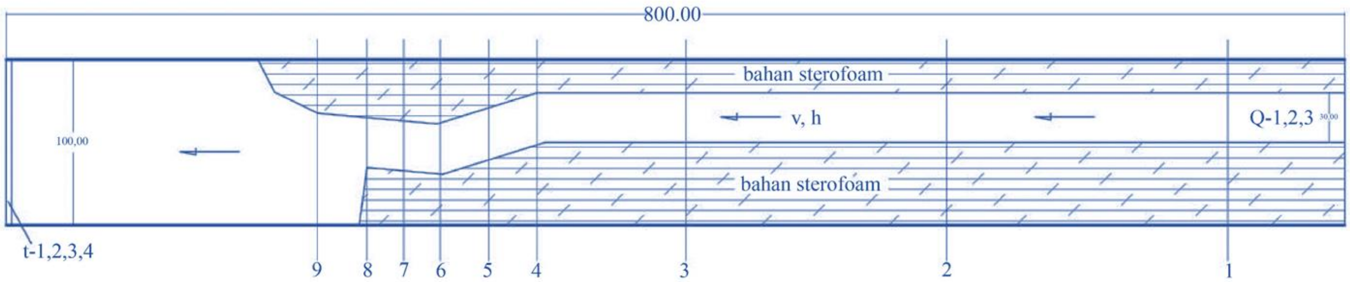


Fig. 1 Flume channel

Some of the studies above inspired the authors to create the Regulate Section Channel Model, which, with the velocity, can flush out the sediment at the mouth of the estuary. Estuaries dominated by waves, tides, river flow, or a mix of these three conditions cause low velocities and sediment, reducing channel performance.

As with the discharge formula $Q = A . v$, by minimizing the cross-section according to the discharge requirements that will exist, the design velocity is obtained.

The initial research hypothesis is that sedimentation and siltation in the mouth of the river can be flushed by designing the velocity by setting the channel cross-section. So, the authors are interested in researching the Regulate Section Channel Model for the Maintenance Channel in the estuary.

2. Materials and Methods

The type of research used is Experimental in the hydraulics laboratory at Hasanuddin University, where these conditions are created and regulated by researchers with reference to field conditions and literature related to research, as well as the existence of controls, with the aim of investigating whether or not there is a causal relationship and how much the magnitude of the causal relationship by providing treatments to several experimental groups and providing controls for comparison.

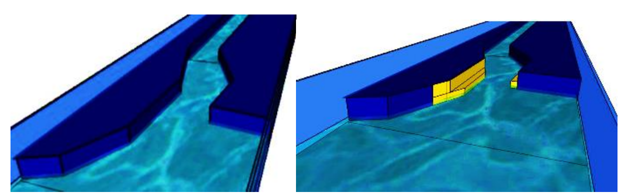
The experiment was carried out on a flume of an experimental channel with a length of 11.5 m, a channel width of 1 m and a height of 0.3 m. The discharge generation is sourced from a pump with a capacity of 8.3 liters/second, and the tidal height is modeled with a spillway with high variations, as shown in Figure 1.

The channel flume is equipped with a water reservoir and circulation tub, a 1.5” PVC pipe as a water circulation network, a stop valve to adjust the water discharge, a digital current meter for measuring water velocity, a stopwatch, a meter for measuring water level and measuring changes in cross-section channels, digital cameras to record (in the form of photos & videos) at each important stage in the research, tables to record research data and for river cross sections made of styrofoam material.

The design scale of the model is made with a height/depth scale of 1:20 and a length/width scale of 1:150. The existing cross-sectional model is made of Styrofoam. for setting square and composite cross-sections made of wood and acrylic for inclined planes.

The section consists of two cross sections, the existing section (square) and the composite section, made in two variations, with a narrowing of 20% and 30% of the channel width, with 3 variations of the model height (h*) for each. As shown in figure 2.

The sediment used is uniformly graded sand according to the Wentworth classification. Segments are determined for the observation point of water level, velocity and sediment in the flume. The observation points for water level and velocity are carried out in 9 segments, one point on the left, middle and right of the section. While the slope for sediment observation is carried out around the mouth of the estuary with a 4 cm grid. The flow rate adjusts to the existing pump capacity. On the downstream side, at the end of the flume, a flood elevation controller is made to model the tidal height. The planned tidal height is 4 elevations, -4.00 cm, 0.00 cm, 6.00 cm and 8.00 cm. Then, carry out experiment variations according to the research plan, as shown in figure 3.



(a) Existing cross-section (square) **(b) Composite Cross Section**
Fig. 2 The regulate section channel model

Fig. 3 Cross section of the estuary on a flume

Table 1. Research model scale

Variable	Notation	Scale
Height/ Depth scale	nH	20
Length Scale	nL	150
Discharge scale	nQ	13,416
Velocity scale	nv	4.47
Time scale	nt	33.54
Acceleration scale	na	0.133

2.1. Model Scale

The determination of the geometric scale is adjusted to the ability and capacity of the flume tank in the laboratory compared to the size of the prototype in the field; this study used distorted models, where the length scale is not the same as the height scale.

The river reference for the estuary cross-sectional model in this study is the Saro River in Takalar Regency, with an average river width of 45 m, so a scale ratio of 1 is determined; 150, a diflume width of 30 cm is obtained. The water depth is adjusted to the pump capacity with a maximum field condition reference of 3 m. With a scale of 1: 50, the depth that is operated in the flume is 6 cm. The experimental scale used on the flume is shown in table 1.

2.2. Research Flow

Make an existing or composite cross-section on the flume and adjust the tidal elevation accordingly by placing flow barriers across the flume, according to research variations. Water is distributed by turning on the pump with the planned discharge *(Q)* according to the planned time *(t)*. Retrieval of data on water level and speed at a specified point carried out for each variation of cross-section, variation of discharge and variation of tides. Furthermore, the sediment is placed at the mouth of the estuary with a determined amount of weight *(kg)*, and water is water by turning on the pump with the planned discharge *(Q)* according to the planned time *(t)*. The water flow was stopped, and the bottom scour profile was recorded at the determined limits using a point gauge. The sediment carried downstream of the flume was weighed, which was carried out in each study variation. The research flowchart is shown in Figure 4.

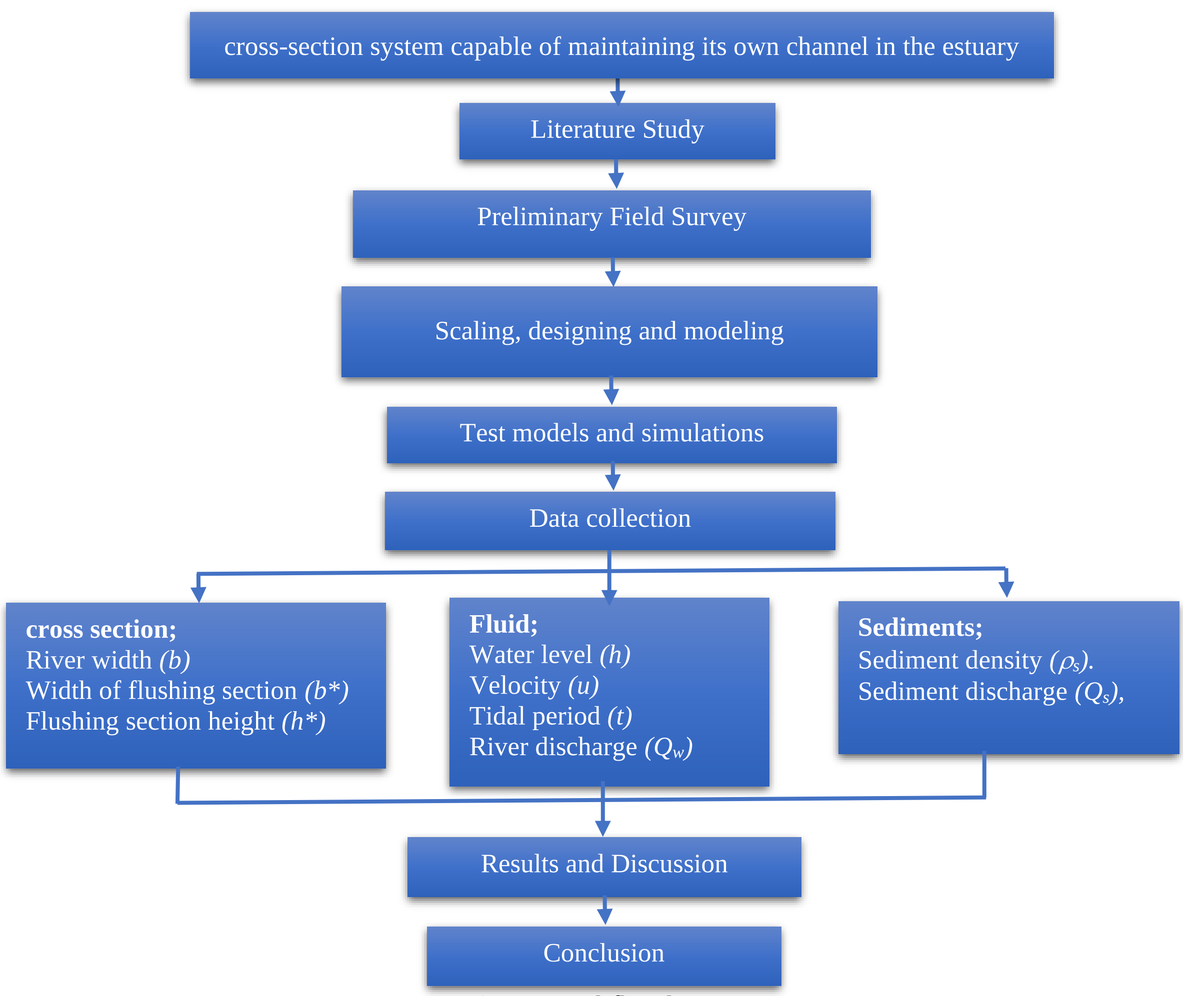


Fig. 4 Research flow chart

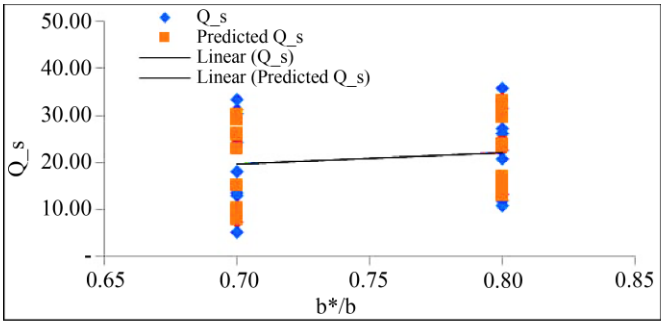


Fig. 5 Effect of composite cross-sectional width ratio $\left(\frac{b*}{b}\right)$ on flushed sediment discharge $\left(Q_s\right)$

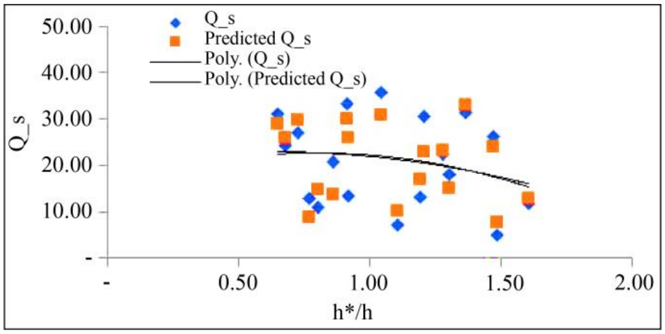


Fig. 6 Effect of composite cross-sectional height ratio $\left(\frac{h*}{h}\right)$ on flushed sediment discharge (Q_s)

3. Results and Discussion

Based on the results of the discussion, some conclusions can be drawn. The variable that affects the research studied is the weight of the sediment flushing $(Qs) = f(channel, discharge, sediment, fluid)$

$$Qs = f(b, b*, h*, h, u, t, Q, g, \rho_w, \mu, \rho_s) \quad (1)$$

This research equation is obtained from calculating the dimensional analysis of the Buckingham method.

$$Q_s = \frac{1}{t}\,\frac{b*}{b}\,\frac{h*}{h}\; b*.h + 2\left(\frac{b-b*}{2}\right).(h-h)\;\frac{\rho_w\,u\,h}{\mu}\;\frac{u^2}{g.h\,(\rho_s-\rho_w)} \quad (2)$$

Where Q_s is the flushing sediment discharge (tons/hr), $\frac{1}{t}$ is the flushing time, $\frac{b*}{b}$ is the area of the cross-sectional width ratio, $\frac{h*}{h}$ is the area of the cross-sectional height ratio, $b*.h + 2\left(\frac{b-b*}{2}\right).(h-h*)$ is the cross-sectional area of the composite (A), $\frac{\rho_W\,u\,h}{\mu}$ is the Reynolds number (Re), and $\frac{u^2}{g.h\,(\rho s-\rho w)}$ is the critical shear stress (τ_{*C}).

3.1. Effect of Composite Cross-Sectional Width Ratio $\left(\frac{b*}{b}\right)$ on Flushed Sediment Discharge (Q_s)

The cross-sectional width ratio $\left(\frac{b*}{b}\right)$ is the ratio of the cross-sectional arrangement width (b*) to the existing Channel width (b). The effect of the ratio $\left(\frac{b*}{b}\right)$ on flushed sediment discharge (Q_s) on the composite cross-section is shown in Figure 5.

From Figure 5, it is shown that in the composite cross-section, the value of the ratio $\left(\frac{b*}{b}\right)$ is directly proportional to the flused sediment discharge (Q_s) which is getting bigger, with a linear trend. Setting the cross-section with a smaller b* affects the increase in speed, which is in line with the increase in flushed sediment (Q_s).

Several previous studies [5] show that the flow velocity is inversely proportional to the cross-sectional area. The larger the cross-sectional area, the lower the flow rate and vice versa. [6] The effect of geometry can reduce kinetic energy (velocity), and higher speeds can provide higher stagnation pressure or uplift. [7] Flow velocity is directly proportional to the depth of the scour. The greater the flow velocity value, the greater the local scour that occurs.

3.2. Effect of Composite Cross-Sectional Height Ratio $\left(\frac{h*}{h}\right)$ on Flushed Sediment Discharge (Q_s)

The ratio of the composite cross-sectional height $\left(\frac{h*}{h}\right)$ is the ratio of the arrangement cross-sectional height (h*) to the water level (h). The effect of the ratio $\left(\frac{h*}{h}\right)$on the flushed sediment discharge (Q_s) on the composite cross-section is shown in Figure 6.

Figure 6 shows that the greater the value of the composite cross-sectional height ratio $\left(\frac{h*}{h}\right)$ will cause the flushed sediment discharge (Q_s) to decrease, with a polynomial trend. This means that the higher the cross-section of the composite (h*), the less effective it is in flushing out the sediment. While the value of the water level (h), apart from being affected by discharge, is also influenced by the height of the tidal water level.

3.3. The Effect of the Reynolds Number (Re) on Flushed Sediment Discharge (Q_s)

The Reynold number (Re) is a number to indicate the nature of laminar or turbulent flow. The effect of the Reynolds number (Re) on the composite cross-section on the flushed sediment discharge (Q_s) as shown in Figure 7.

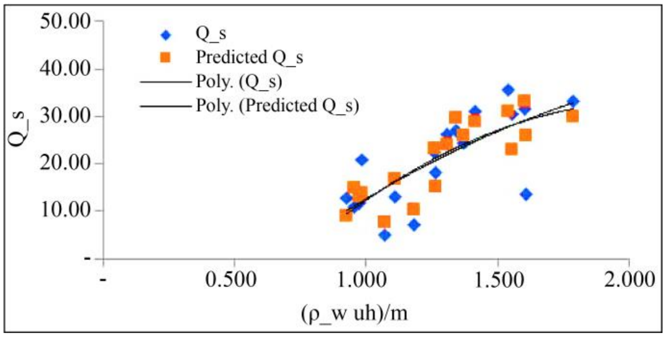


Fig. 7 The effect of the reynolds number (Re) on flushed sediment discharge (Q_s)

From Figure 7. It is shown that on the arrangement composite cross-section, the greater the Reynolds number (Re), the greater the flushed sediment discharge (Q_s), with a polynomial trend. The Reynolds number is the ratio of the inertial force to the viscous force. The inertial force, which is affected by the greater flow velocity, results in an increase in sediment flushing. (Q_s).

This is in accordance with several previous studies [8]. Reynolds number of flow occurs due to the impact of fluid turbulence. [9] Reynolds number is used in the analysis of sediment transport. In this case, the velocity becomes the shear velocity, and the hydraulic radius becomes the diameter of the grain forming the groove base.

3.4. Effect of Critical Shear Stress (τ_{*C}) on Flushed Sediment Discharge (Q_s)

The critical shear stress (τ_{*C}) is the number to determine which sediment grains begin to move. The effect of the critical shear stress (τ_{*C}) on the composite cross section on the flushed sediment discharge (Q_s) as shown in Figure 8.

From Figure 8. It is shown that at the arrangement of the compositional cross-section, the greater the critical shear stress (τ_{*C}). The greater the flushed sediment discharge (Q_s), with a polynomial trend. Where the critical shear stress (τ_{*C}) is an estimate to determine sediment movement, with the influential parameter being velocity, to the sediment density.

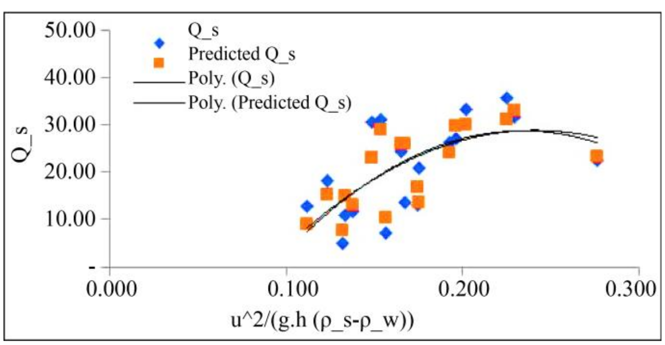


Fig. 8 Effect of critical shear stress (τ_{*C}) on flushed sediment discharge (Q_s)

The greater the speed, the greater the critical and linear shear stress on the volume of flushed sediment discharge (Q_s).

In several related studies, such as [10], Shear stress increases nonlinearly with increasing pillar diameter and scour depth. [11] The thickness of sediment deposits affects the critical shear stress at low sediment base thickness, and this effect will decrease with increasing sediment base thickness. [12] the critical shear stress is negatively affected by the particle diameter and positively affected by the internal friction angle of the soil. [13] The critical shear stress increases with decreasing water content, decreasing void ratio, increasing unit weight, and increasing consolidation stress. [14] Significant differences in the effect of critical shear stress on high, medium, and low tides are influenced by differences in sediment distribution. [15] the effect of bed shear stress and water depth has a high correlation coefficient. Similarly, the effect of bed shear stress on total scour shows a high correlation coefficient.

3.5. Sediment Flushing Patterns

Sediment flushing patterns are displayed in the form of scour contours based on the observed depth data at 301 observation points with the help of a grid with a distance of 4cm. The flushing pattern displayed is the value after running in 1 tidal period, from the lowest peak-tide elevation with a time scale of 1: 33.54, at high tide 7 hours in the field = 12.52 minutes in the laboratory, at low tide 16 hours in the field = 28.62 minutes. The cross-sectional perspective on the estuary and the grid system is shown in Figures 9 and 11.

Based on Figure 8 – 10, the flushing pattern on the existing cross-section occurs in the upstream area at a rectangular cross-section setting of 20% and 30%. It can be seen that there is a process of sediment deposition in the upstream part of the river and scour in the downstream part of the estuary mouth area, where the amount of material (Qs) The amount of deposited and eroded increases with the percentage of arrangement composite cross-section, but the arrangement cross-section with too large a percentage, seems to change the scour deposition to the upstream area.

Several related studies, such as [16] Study results show, show that each pillar shape has a different character: the deepest scour at the side points of the pillar, from the first minute to the 20th minute, sudden deep scour, and the shape of the river bed around the pillar rises and falls irregularly.

From the 20th minute until the end of the stream, the decrease in scour was almost linear, and the scour lines were even. In general, pile-shaped pillars have the shallowest scour compared to other pillar shapes, so the optimum pillar shape is the pile-shaped pillar. [17] The study's results showed that the flow rate during the test was 9.278 l/s. The mean grain gradation value (d50) was 0.39 mm, and there was movement of the bed scour grain (live bed scour).

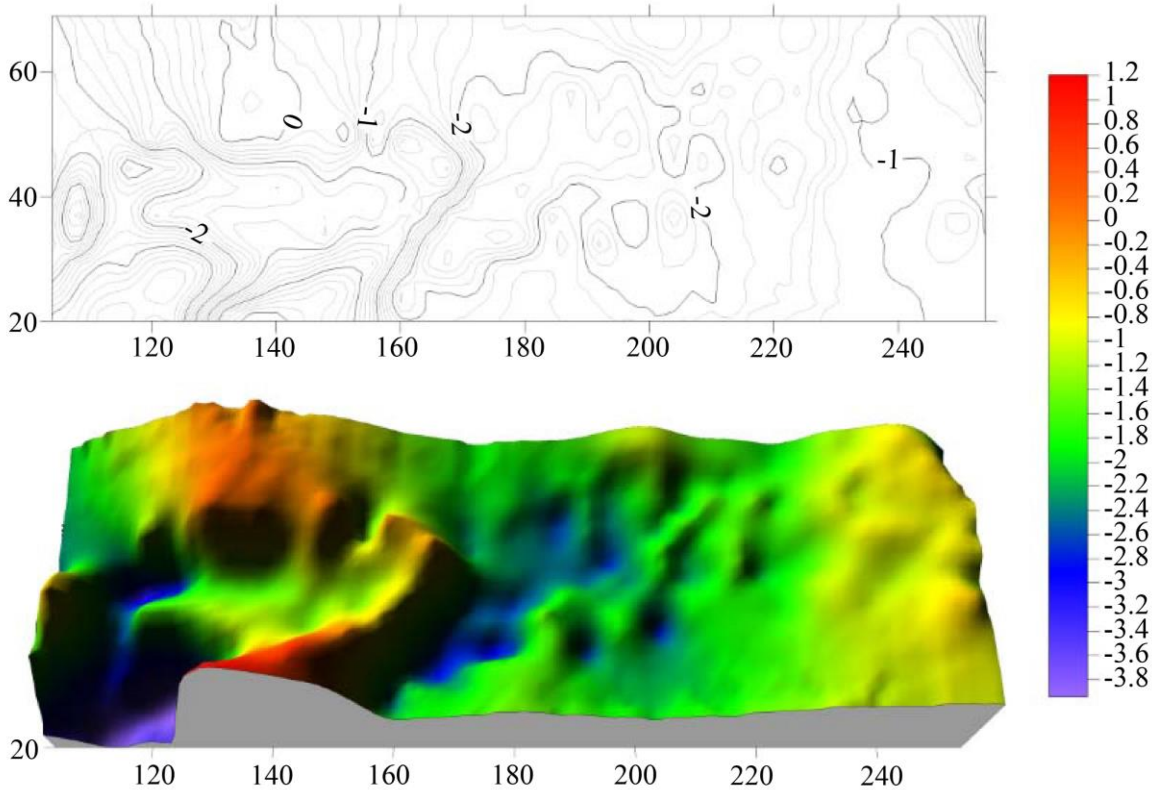


Fig. 9 Sediment flushing patterns on existing cross-section (square)

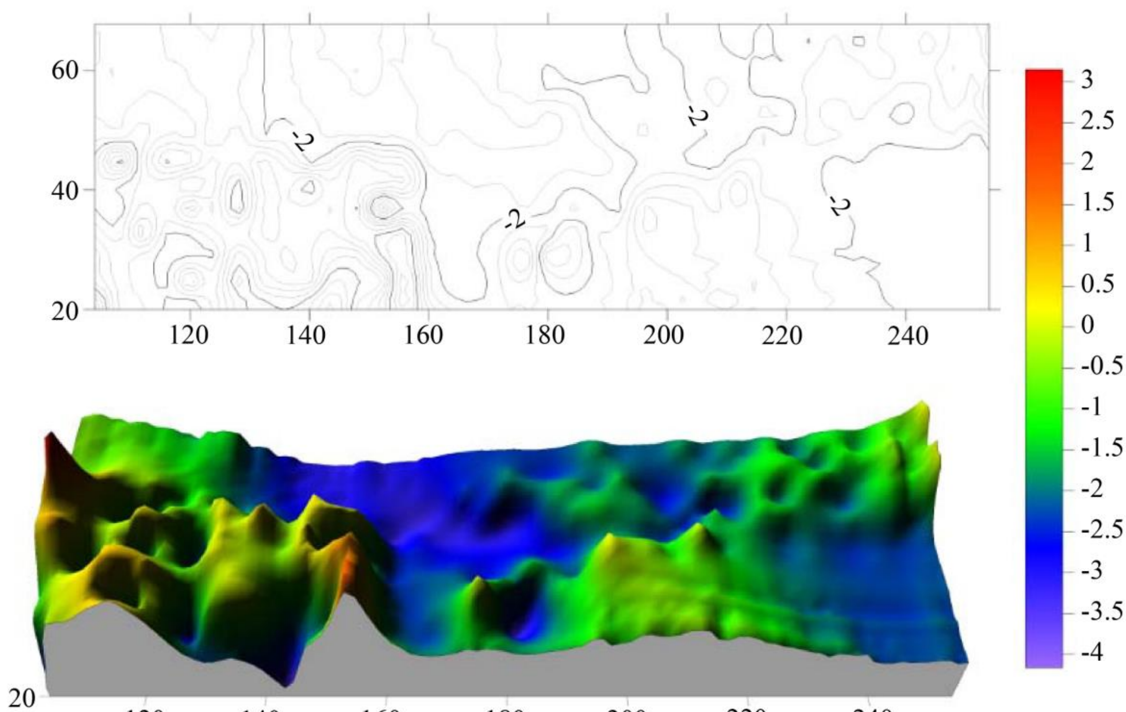


Fig. 10 Sediment flushing pattern on composite cross-section 20%

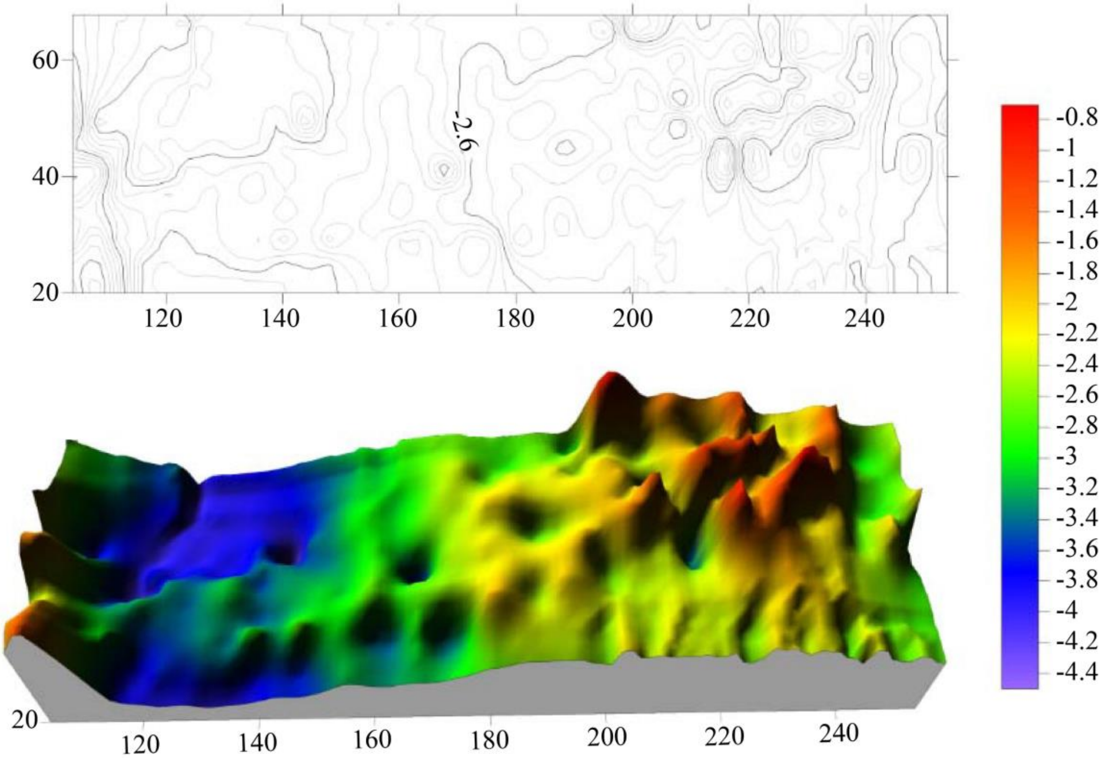


Fig. 11 Sediment flushing pattern on composite cross-section 30%

The research results show that the type of flow that occurs when running is sub-critical and turbulent. The maximum scour conditions occurred at STA 16 on the front side of the upstream pillar, which was 0.017 m at a flow depth of 0.04 m, and sediment material accumulated at the downstream side of the pillar. The maximum scour depth at 0.05 of 0.014 m occurs at STA 15 on the side of the front of the pillar, and the maximum scour depth at 0.06 m of 0.010 m occurs at STA 15 on the side of the front of the pillar.

The depth of flow affects the depth of the scour; the more the flow, the smaller the scour. The scour patterns on the cylindrical pillars with various flow depths are relatively the same, even with the width and depth. [18] The results showed that the treatment of the abutments affected the depth of the scour that occurred. As a result of being deflected 90°, the scour depth at points 1, 3, and 4 was reduced by 17.8%, 20.5%, and 24.3%, respectively, compared to the scour at the abutments without treatment. In contrast, due to the placement of the orifice, the scour depth at points 1, 3 and 4 decreased by 21.6%, 24.3% and 30.4%, respectively. The treatment of the abutments also changes the pattern of different scour distributions.

3.6. Comparison of Sediment Flushing in Estuaries

Comparison of Sediment Flushing in this study was carried out by comparing the measured sediment data and the bottom sediment transport equation (q_s) from the Einstein and Meyer Peter Muller (MPM) equations, as shown in figure 12.

Figure 12 shows that the discharge of flooded sediment tends to be high at Q3 (Q max.) at Qs, indicating a significant increase in discharge in sediment flushing. The calculation of the MPM method tends to represent the conditions in this study or is in the middle.

In several related studies, such as [19, 20], the results of sediment transport analysis with the Einstein method are greater in transport results compared to the M.P.M. method.

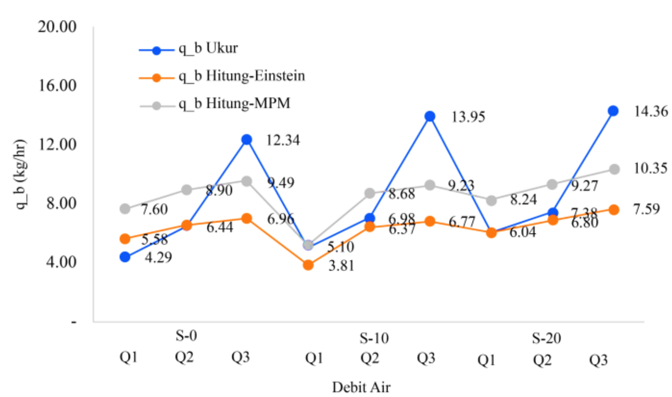


Fig. 12 Comparison of sediment flushing in estuaries

The difference in the amount of sediment transport is caused by the flow conditions at the four different sections. [21] The difference in the calculation results (higher value of the MPM results than Einstein) could be caused by several things, including the following: 1. Using different discharge data, 2. River geometry data with different measurement times.

Calculations performed using the MPM equation give results that are close to the results of measuring changes in the geometry of the river. [22] Of the 4 methods used, Meyer Peter Muller and Einstein's method is the most suitable for estimating the Langgar Trench sedimentation rate.

In the Meyer Peter Muller method, the highest sedimentation rate occurred at point 1 during low tide, 6.93 tons/day, and the lowest occurred at point 5 during low tide, 1.26 tons/day. In the Einstein method, the highest sedimentation rate occurs at point 1 during low tide, which is 6.99 tons/day, and the lowest occurs at point 5 during low tide, which is 1.31 tons/day.

4. Conclusion

From the results and discussion, it can be concluded that the greater the value of the composite cross-sectional width ratio, the greater the Reynolds number, the greater the critical shear stress causes flushing sediment discharge is greater, the composite cross-sectional height ratio which is larger causes flushing sediment discharge to decrease, the flushing pattern occurs when sediment deposition occurs in the upper reaches of the river and scours downstream in the estuary mouth area, where the amount of deposited and eroded material increases as the percentage of composite cross section is large, but setting the cross-section with a percentage that is too large, seems to change the scour deposition to upstream area. The Meyer Peter Muller (MPM) equation is closer to this research.

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References

[1] Julie Dean Rosati et al., "Coastal Inlet Navigation Research in the U.S. Army Corps of Engineers," *Coastal Dynamics*, vol. 7, pp. 15-24, 2013. [Google Scholar] [Publisher Link]

[2] Mir-Jafar-Sadegh Safari, Mirali Mohammadi, and Golezar Gilanizadehdiza, "On the Effect of Cross-Sectional Shape on Incipient Motion and Deposition of Sediments in Fixed Bed Channels," *Journal of Hydrology and Hydromechanics*, vol. 62, no. 1, pp. 75-81, 2014. [CrossRef] [Google Scholar] [Publisher Link]

[3] Laurent Schindfessel, Stéphan Creëlle, and Tom De Mulder, "Influence of Cross-Sectional Shape on Flow Patterns in an Open-Channel Confluence," *E-Proceedings 36th IAHR World Congress*, vol. 32, no. 1989, pp. 495-502, 2015. [Google Scholar] [Publisher Link]

[4] Lucas Silveira et al., "Integrated Method for the Development of Optimal Channel Dredging Project," *Terra et Aqua*, no. 146, pp. 5-16, 2016. [Google Scholar] [Publisher Link]

[5] Kukuh Wisnuaji Widiatmoko, and Fahrudin Ahmad, "The Influence of Cross-Section Width on the Rate and Discharge of Rice Field Irrigation Flow in Sambirejo Village, Grobogan," *Journal of Disprotek*, vol. 12, no. 2, pp. 97-102, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[6] Tohidi, and Farzam Safarzadeh Maleki, "Cross-Section Influence on Velocity Distribution and Energy Dissipation of a Moderately Sloped Spillway Chute Flow," *6th International Symposium on Hydraulic Structures*, pp. 1-11, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[7] D. Pradana et al., "Analysis of Scour around the Pillar of the Pappa' River," *Jurnal Rekayasa Infrastruktur Hexagon*, vol. 6, no. 2, pp. 58-67, 2021. [Google Scholar]

[8] M. Afkhami, A. Hassanpour, and M. Fairweather, "Effect of Reynolds Number on Particle Interaction and Agglomeration in Turbulent Channel Flow," *Powder Technology*, vol. 343, pp. 908-920, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] PUPR, River Hydraulics Module, 2017. [Online] Available: https://simantu.pu.go.id/epel/edok/791dd_05._Modul_5_Hidrologi_dan_Hidrolika_Sungai.pdf

[10] Abhishek Chougule et al., "Critical Shear Stress near Bridge Pier for Non-Uniform Sediments," *Proceedings of National Conference on Technological Developments in Civil and Mechanical Engineering(NCTDCME-18)*, pp. 41-45, 2018. [Google Scholar] [Publisher Link]

[11] Charles Hin Joo Bong et al., "Deposition Thickness and Its Effect on Critical Shear Stress for Incipient Motion of Sediments," *Journal of Teknologi*, vol. 78, no. 9, pp. 21-30, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[12] Xingyu Yuan et al., "Estimating the Critical Shear Stress for Incipient Particle Motion of a Cohesive Soil Slope," *Scientific Reports*, vol. 12, no. 1, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[13] Reza Rahimnejad, and Phillip S.K. Ooi, "Factors Affecting Critical Shear Stress of Scour of Cohesive Soil Beds," *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2578, no. 1, pp. 72-80, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[14] Xiao-Lei Liu et al., "Sediment Critical Shear Stress and Geotechnical Properties along the Modern Yellow River Delta, China," *Marine Georesources and Geotechnology*, vol. 36, no. 8, pp. 875-882, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[15] Marta Kiraga, and Zbigniew Popek, "Bed Shear Stress Influence on Local Scour Geometry Properties in Various Flume Development Conditions," *Water*, vol. 11, no. 11, pp. 1-15, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Sarwono Sarwono, "Study of Local Scouring Characteristics Surroundings Several Bridge Pilars Forms," *Jurnal of Sumber Daya Air*, vol. 12, no. 1, pp. 89-104, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[17] E.R. Yanuar, and N.M. Putri, "*Analysis of the Influence of Flow Depth on Scour Patterns Around Cylindrical Pillars*," Tugas Akhir thesis, University Technology Yogyakarta, 2018. [Google Scholar] [Publisher Link]

[18] Nina Shaskia, and Maimun Rizalihadi, "Local Scour Patterns Due to Treatment of Bridge Abutments," *Civil Engineering Journal*, vol. 8, no. 2, pp. 60-67, 2019. [Google Scholar] [Publisher Link]

[19] Tommy Jansen, Roski R.I. Legrans, and Pingkan Pratasis, "The Effect of Tide to Current and Sedimentation Pattern in Amurang Bay, North Sulawesi," *SSRG International Journal of Civil Engineering,* vol. 6, no. 10, pp. 14-22, 2019. [CrossRef] [Publisher Link]

[20] Janur Hasim, "*Analysis of Sediment Transport in the Jangkok High-Level Diversion (HLD) Channel - Babak Using M.P.M and Einstein Methods*," S1 thesis, Universitas Mataram, 2017. [Google Scholar] [Publisher Link]

[21] Tiny Mananoma, Sudjarwadi, and Djoko Legono, "Prediction of Sediment Transport in Rivers to Control Water Damage," *Pertemuan Ilmiah Tahunan HATHI XXII*, pp. 23-25, 2005. [Google Scholar] [Publisher Link]

[22] Rendy Siswanto, Kartini Kartini, and Henny Herawati, "Study of the Characteristics and Rate of Sediment Transport in the Langgar Ditch, Wajok Downstream Village, Siantan Sub-District, Mempawah District," *JeLAST: Jurnal PWK, Laut, Sipil, Tambang*, vol.8, no. 2, pp. 1–9, 2021. [CrossRef] [Google Scholar] [Publisher Link]