Journal of Water Resources Management, Vol. 2 No. 2 (2024) p. 1-5

JOWRM

Journal of Water Resources Management

Journal homepage: https://journal.water.gov.my

e-ISSN: 2811-3578

Investigation of Factors Affecting Tidal Damping In Estuaries

A. R. Nurtashafizrah[1], Prof Ir. Dr. Lee Wei Koon[2]

[1]Division of Special Project, Department of Irrigation and Drainage Malaysia, 63000 Cyberjaya

[2]Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM)

Email: [a]nurtashafizrah@water.gov.my, [b]leewei994@salam.uitm.edu.my

Received 7 August 2024;
Accepted 26 December 2024;
Available online 27 December 2024

Abstract: Both in the water column and in the sediment, the mix of seawater and freshwater contains high levels of nutrients. Due to this condition, it makes the estuaries as a preferable location for natural habitats in the world. These typical features show the essential roles in the life cycle of many species in the estuarine environment. Three (3) locations of estuary in the Perak state have been selected namely Perak, Bernam and Kurau estuary because of these three estuaries are the main river basin in the state. In general, the theoretical work is carried out to study the fundamental properties of tidal dynamics in estuaries for the analysis of tidal properties and geometry. Several previous papers have been published on tidal damping and wave propagation analytical methods. The tidal amplification is the outcome of the imbalance between topographic convergence and friction. If the value of convergence is greater than friction, the wave amplification is occurred; if the friction value is greater than convergence, the wave is damped. However, if both convergence and friction equally strong, the result is constant tidal range. Therefore, by having the investigation of tidal damping in estuaries, this will enhance the understanding of geometric parameters (e.g: river discharge, tidal discharge, convergence length, average cross-sectional area, tidal velocity and etc.); tidal movement (e.g: tidal damping or amplification); and the relationship between tidal range and the factor affecting tidal damping.

Keywords: Tidal damping, Wave amplification, Estuary, Tidal velocity

1. Introduction

An estuary is a partially enclosed coastal body of brackish water with a free one access to the open sea with one or more rivers or streams flowing into it (Pritchard, 1967). Both estuaries are subject to coastal effects such as tides, waves, and saline water influx, as well as riverine influences such as freshwater and sediment flow. In both the water column and the soil, the mixture of seawater and freshwater provides high nutrient levels, rendering estuaries one of the most active natural estuaries in the world. (Elliott et al., 2004).

An estuary is a dynamic ecosystem connected to the open sea, from which sea water joins the rhythm of the tides. The salt water entering the estuary dilutes the fresh water that comes from rivers and streams. The pattern of dilution varies between various estuaries and depends on the volume of freshwater, the tidal range and the degree of evaporation of water to the extent of the estuary's water evaporation. (Elliott et al., 2004).

The natural variations of river flow into estuaries are significantly altered by the increase in human activities such as dam construction, flow diversion, land reclamation, dredging and freshwater withdrawal or natural as global sea level rises. (Schuttelaars et al., 2013; Winterwerp et al., 2013). These operations affect tidal damping and the propagation of tidal waves.

The coastline of Perak extends 174km along the west coast of Peninsular Malaysia which from Sg Kerian at the Pulau Pinang border in the north to Sg Bernam at the Selangor border in the south. The National River Mouth Study in Malaysia (1994) carried out by JICA reported that some dredging works have been carried out in two (2) rivers in Perak which Sg Beruas and Sg Dinding. Due to the importance of Sg Dinding where the Lumut Maritime Terminal is situated upstream of the river mouth more periodic maintenance dredging has been carried out even in recent time.

Several studies have been carried out on the effect of intrusions of human activities along the estuaries for examples in sediment properties (Bai et al. 2003; Hossain et al. 2004; Kim et al. 2006; Li 2010), morphology (Barusseau et al. 1998; Blott et al. 2006; Xie et al. 2009; Jeuken and Wang 2010), ecosystems (Edgar and Barrett 2000; Byun et al. 2005; Smith et al. 2006; 2010), hydrological regime (Hoa et al. 2007; Luo et al. 2007; Liria et al. 2009; Zhang et al. 2010) and flow reduction and dredging (Godin 1999; Horrevoets et al. 2004; Cai et al. 2012b). Just a few studies have investigated the effect of tidal damping in estuaries (Zhang et al. 2012; Cai et al. 2012a).

In addition, for spatial variables such as velocity amplitude, tidal amplitude, wave celerity, and phase lag of tidal propagation, the fully analytical equations are taken into

**Corresponding author: nurtashafizrah@water.gov.my*

account, which display the effect of river discharge comparable to that friction. The residual slope due to nonlinear friction appears to have been taken into account, which can significantly influence the propagation of tidal waves when the impact of river discharge is included, especially in the upstream part of the estuaries (Vignoli et al. 2003).

On the basis of Langhein (1963) and Dyer (1973), the difference between topographical convergence and friction is the product of tidal amplification. The wave is amplified if convergence is greater than the effect of friction. Meanwhile, if the friction is greater than the convergence effect, the wave is damped. The tidal range is constant if they are equally strong. A strong relation between tidal damping and wave celerity appears to exist. The tidal damping and the celerity of tidal wave both respond to the discrepancy of convergence and friction.

In estuaries where tidal damping is noticeable, a major deviation from the classical wave celerity can be observed. If the wave is intensified, the wave travels much faster than the celerity. Meanwhile, when the wave is damped, the wave travels even slower. It can be a direct perception of the interaction between tidal damping, wave celerity and river flow by providing these analytical relationships, which can be useful for further research in the river mouth that undergo main stream flow in a coastal area.

In this analysis, it can be seen that the tidal damping is mainly influenced by discharge of river through the term of friction, convergence, tidal range, river discharge and wave celerity. The goal of this study is therefore to investigate the tidal damping in estuaries of three (3) locations in the state of Perak by using the secondary data obtained from Department of Irrigation and Drainage (DID) and Department of Survey and Mapping Malaysia (JUPEM); identified the tidal movement; and identified the relationship between tidal range and factor affecting tidal damping in estuaries.

1.1 Tidal Movement and Amplification

The tidal movement has an influence on the equation of water balance as well as the E/H ratio of value to wave celerity. Based on previous research by Langbein (1963) and Dyer (1973), the discrepancy among climatic convergence and friction is the product of tidal amplification. The wave is amplified when convergence is stronger than friction, but if friction is stronger than convergence, the wave is damped. Meanwhile, the tidal range is constant if they are equally strong. This was definitely seen in Jay's (1991) perturbation theory and merged the previous section's Langrangean equations with Savenije's (1998) momentum balance equation.

There is a similar interaction between tidal damping or amplification and wave celerity, in which the difference between convergence and friction responds to tidal damping and tidal wave celerity. A major deviation from the classical wave speed in estuaries where tidal damping or amplification is occurs can be observed.

If the wave is amplified, the wave travels considerably faster than the celerity. Meanwhile, the wave travels much slower as the wave is damped. Figure 2.1 below presents the observations of tidal wave celerity under tidal damping and amplification for the Schelde in the Netherlands. It clearly indicates that the travel time is much shorter in an amplified wave estuary than the travel time and that the travel time in damped estuary is much greater.

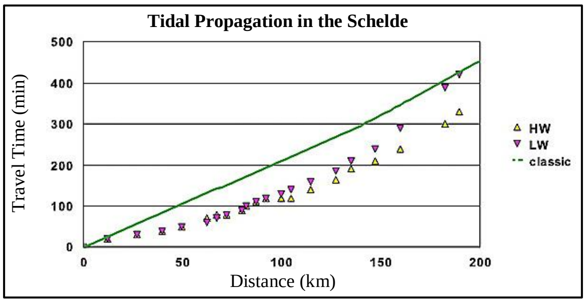

Figure 2.1: Observed Tidal Wave Propagation at HW and LW on 21 June 1995 in the Schelde as Opposed to the Classical Equation Propagation

The damping of the velocity magnitude is relatively similar to the damping of the tidal range, including the error term, based on Savenije (2012). If the phase lag, ε and the damping/amplification are fixed, this means exponential damping or no damping. This theory is valid in long estuaries that slowly transform into a flow, and the assumption might not even be accurate and will use a basic linearized formula which functions in short and closed estuaries under some circumstances.

1.2 Estuary Number

The tide and the stream flow are the two-primary estuary-shape mechanisms. The easiest dimensionless number characterizing the ratio is the number of the estuary N, which called the number of Canter-Cremers in the Dutch literature, equivalent to the ratio of the sum of fresh and saline water that flows into the estuary during a tidal cycle.

$$N = \frac{Q_f T}{P_t}$$

Where $N = Estuary\ number$

$Q_f = Fresh\ water\ discharge$

$T = Tidal\ period$

$P_t = Flood\ volume\ or\ tidal\ prism$

Another essential estuary number is the Estuarine Richardson number, defined as the ratio of potential energy given to the estuary by the discharge of the river through fresh water buoyancy and the kinetic energy provided by the tide during a tidal cycle.

$$N_R = \frac{\Delta_\rho}{\rho}\frac{gh}{v^2}\frac{Q_f T}{P_t}$$

This number of estuaries represents more driving forces than the Canter-Cremers number, which is associated with the effect of the differential of relative density between freshwater and seawater, and the Froude number, F which is the ratio between the amplitude of tidal velocity, v and the celerity of the finite amplitude wave of non-friction, c_o

$$F = \frac{v}{c_0} \qquad where\ c_0 = \sqrt{gh}$$

Published by JPS Publishing
https://journal.water.gov.my

In the river discharge, there is enough energy available to maintain a sharp interface, and if the Estuarine Richardson number is strong, stratification occurs subsequently. In addition, if it is low, there is enough energy available to blend the river water with saline water in the tidal currents and the estuary is well mixed.

1.3 Factor Affecting Tidal Damping

There are features, both a river and a sea, of an estuary. The typical riverside characteristics of an estuary are that it has banks, flowing water, sediment transport, occasional floods, and fresh water. His normal marine characteristics are the presence of tides and saline water. The most common characteristic of an estuary is the transition between a river and a sea with its own hydraulic, morphological and biological characteristics, such as tidal waves of a mixed nature, a funnel shape, and a brackish environment, somewhat different from other bodies of water.

The effect of the imbalance between topographic convergence and friction is tidal damping or amplification. Several variables, such as river discharge, friction term, wave celerity, etc., influence it. Similarly, if the tidal wave is damped, the speed of propagation is lower. In the Schelde estuary (located in the Netherlands and Belgium) and in the Incomati estuary in Mozambique, this phenomenon is clearly observed. The tidal wave is damped in the Incomati and the wave's celerity is lower as predicted.

River discharge primarily influences tidal damping via a friction cycle as a tide propagates into the estuary, attenuating tidal motion by raising the numerator's quadratic velocity, while decreasing the effective friction by increasing the water depth of the denominator. The third consequence of river discharge, according to Savenije et al. (2012), leads to a weakening of channel convergence, such as a decrease in the width and/or depth of the channel along the Yangtze River estuary. The findings indicate that with rising river discharge, there is a vital benefit of river discharge that reduces tidal damping.

Intense scientific interest has long been the impact of river discharge on tidal wave propagation, especially on tidal damping in estuaries, such as Dronkers, 1964; LeBlond, 1979; Godin, 1985, 1999; Jay, 1991; Horrevoets et al., 2004; Kukulka and Jay, 2003b; Cai et al., 2012b, 2014b, 2016; Guo et al., 2015; Leonardi et al., 2015; Alebregtse and de Swart, 2016; Zhang et al., 2018a. It is worth noting that, Conventional methods for analyzing tidal signals (such as harmonic and Fourier analysis) are limited due to the assumption of stationary signals. Due to the correct understanding of tidal wave behavior under the influence of river discharge, non-stationary tidal harmonic analysis was generated to better account for the nonlinear tide-river interactions such as Jay and Flinchem, 1997, 1999; Kukulka and Jay, 2003a; Jay et al., 2011, 2015; Matte et al., 2013, 2014).

There appears to be a close relationship between tidal damping or amplification and wave celerity, where both tidal damping and tidal wave celerity respond to the imbalance between convergence and friction, where tidal damping or amplification is apparent, a substantial variance can be observed in estuaries from the classical wave celerity c0.The wave travels much faster than the speed if the wave is intensified. Meanwhile, the wave moves considerably more slowly when the wave is damped.

2.0 Results and Discussion

The estuary has special characteristics of both a river and a sea. The typical feature of the estuary is the transition of water between a river and a sea with its own hydraulic, morphology and biologic characteristics. The estuary is very important to people because lands bordering estuaries usually have great potential for agriculture activities and residential area due to its fertile soils and flat land.

Basically, the investigation of tidal damping in estuaries for three (3) locations of estuary namely Perak, Bernam and Kurau estuary is carried out in this study based on evaluation of geometry parameters, identification of tidal movement and identification of factor affecting tidal damping in estuaries.

2.1 Evaluation of Geometry Parameters

In this study, three (3) location of estuary is selected namely Perak, Bernam and Kurau estuary. The summary data of the geometry and tidal characteristics of Perak, Bernam and Kurau estuary. Cross-sectional areas have been calculated by reference to the mean tidal level observed and not by reference to any survey dates or temporary benchmarks which are not available.

From the summary, the result shows that the discharge is influenced by the cross-sectional area and velocity of the water. For example, the Sg. Bernam under Bernam estuary shows the higher value of discharge which is 57.40 m^3/s; followed by Sg. Plus and Sg. Chendering (under Perak estuary) which are 27.33 m^3/s and 13.40 m^3/s respectively. Meanwhile, Sg. Kurau at Pondok Tanjung and Sg. Kurat at Bt. 14 Jln Taiping show the lower value of discharge which are 0.68 m^3/s and 2.50 m^3/s respectively. This situation is happened due to increases the width, depth and cross-sectional area will lead to increases the discharge.

For geometry parameters of estuary by exponential function, the shape model can be applied in multi-channel and multi-reach estuaries. In general, an estuary that does not experience strong ocean waves near the mouth can be described as having a single reach with only one convergence length, while it normally has two reaches with two convergence lengths for estuaries that experience strong waves near the mouth; a short reach near the sea with a short convergence length and a long one upstream with a longer convergence length. Therefore, all the estuaries tend to consist of one cross-sectional region and convergence duration of width for this analysis. It shows that near the mouth of the estuary, the convergence period is shorter, indicating the area dominated by the wave relative to the portion after the inflection point dominated by the tide.

2.2 Identification of Tidal Movement

Tidal movement is the variations of water level and water velocity tidally dominated differ according to periodic functions which water level rises and falls periodically at the estuary mouth.

Published by JPS Publishing
https://journal.water.gov.my

Based on Savenije (2012), the convergence term C_c and friction term f are obtained to categorize the tidal movement occurs in the estuary. In this term, the depth h is preferred instead of the hydraulic radius. This assumption is justifies if the estuary is wide in relation to its depth which B>h. Both value of this term is dimensionless. The value is determined by using the equation below:

$$C_C = \frac{v}{b} \quad where\ v = velocity; b = convergence\ length$$

$$f = \frac{1}{1 - \left(\frac{H/h}{2}\right)^2} \quad where \frac{H}{h} = ratio\ of\ tidal\ range\ to\ stream\ depth$$

The results show that convergence term value for Perak, Bernam and Kurau estuary is 0.0017, 0.0008 and 0.0008 respectively. As we can see, the value of convergence is smaller than friction term. According to previous authors, such as Langbein (1963) and Dyer (1973), the wave is enhanced if convergence is greater than friction, and the wave is dampened if convergence is smaller than friction. The tidal range, however, is constant if both are equally strong. There appears to be a similar relationship between tidal damping and wave celerity, in which the wave travels much faster if the wave is intensified. If the wave is damped, however, the wave travels significantly more slowly.

The celerity equation shows that the decreased storage width ratio value of rS explicitly results in a higher propagation velocity that is inversely proportional to the root of rS. The pace increases even more as a second order consequence, since the convergence term increases compared to the friction term. In the Damping equation, higher wave celerity corresponds to less damping and more amplification. Therefore, the tidal movement for the Perak, Bernam and Kurau estuary can be graded as damping due to the frictional value far greater than the convergence value from the results obtained.

3.0 Conclusion

It is shown that there is indeed the relationship between geometry parameters, tidal range and tidal movement (amplification/damping) in the estuary. This relation can be expressed by a simple combination of hydraulic geometry and analytical analysis. It is approved that the wave is damped if the convergence smaller than friction. In addition, the friction, wave celerity, tidal range, convergence length and Froude number give significant affect to tidal damping in estuary. If the value of convergence is greater than friction, the wave amplification is occurred; if the friction value is greater than convergence, the wave is damped. However, if both convergence and friction equally strong, the result is constant tidal range.

Acknowledgement

The author would like to express their gratitude to The Department of Irrigation and Drainage Malaysia for funding this research.

References

[1] Cai, H., Savenije, H. H. G., and Toffolon, M., (2012a). A New Analytical Framework For Assessing The Effect Of Sea-Level Rise And Dredging On Tidal Damping In Estuaries, J. Geophys. Res., 117, C09023, doi:10.1029/2012JC008000.Strunk, W., Jr., & White, E. B. (1979). The elements of style (3rd ed.). New York: MacMillan.

[2] Cai, H., Savenije, H. H. G., Yang, Q., Ou, S., and Lei, Y., (2012b). Influence of River Discharge And Dredging On Tidal Wave Propagation; Modaomen Estuary Case, J. Hydraul. Eng., 138, 885–896, doi:10.1061/(ASCE)HY.1943-7900.0000594.

[3] Dronkers, J.J., (1964). Tidal Computations In Rivers And Coastal Waters. North-Holland Publishing Company, Amsterdam.

[4] Dalrymple, R.W. and Choi, K. (2007) Morphologic and Facies Trends Through The Fluvial–Marine Transition In Tide-Dominated Depositional Systems: A Schematic Framework For Environmental And Sequence-Stratigraphic Interpretation. Earth-Science Reviews 81: 135–174

[5] Friedrichs, C.T., Aubrey, D.G., (1994). Tidal Propagation In Strongly Convergent Channels. Journal of Geophysical Research-Oceans 99, 3321{3336.

[6] Friedrichs C.T., (1995). Stability Shear Stress And Equilibrium Cross-Sectional Geometry of Sheltered Tidal Channels. J.Coast.Res. 11: 1062-1074

[7] Friedrichs, C.T. (2011) Tidal Flat Morphodynamics: A Synthesis. In: Treatise on Estuarine and Coastal Science, vol. 3, Estuarine and Coastal Geology and Geomorphology. Ed.:J. D. Hansom and B. W. Fleming, Elsevier, Amsterdam: 137-170

[8] Gisen, J.J.A., Savenije, H.H.G., Nijzink, R.C. and Abd. Wahab, A.K., (2015). Testing a 1-D Analytical Salt Intrusion Model and Its Predictive Equations In Malaysian Estuaries, Hydrological Sciences Journal, 60:1, 156-172, DOI: 10.1080/02626667.2014.889832

[9] Horrevoets, A. C., Savenije, H. H. G., Schuurman, J. N., and Graas, S., (2004). The Influence Of River Discharge On Tidal Damping In Alluvial Estuaries, J. Hydrol., 294, 213–228.

[10] Jay, D.A., (1991). Green Law Revisited - Tidal Long-Wave Propagation In Channels With Strong Topography. Journal of Geophysical Research-Oceans 96, 20585{20598.

[11] Lorentz, H.A., (1926). Verslag Staatscommissie Zuiderzee (in Dutch). Algemene Landsdrukkerij, The Hague, Netherlands.

[12] Langbein, W., (1963). The Hydraulic Geometry of A Shallow Estuary. Bull. Int. Ass. Scient. Hydrol. 8, 84{94.

[13] Nienhuis, J.H. (2016) Plan-view evolution of wave-dominated deltas. PhD thesis, Twente University

[14] Pillsbury, G., (1939). Tidal hydraulics. Corps of Engineers, Vicksburg, USA.

[15] Postma, H. (1967) Sediment Transport and Sedimentation In The Estuarine Environment. In: Estuaries. Ed.: G.H.Lauff, Am.Ass.Adv.Sci. 83, Washington, D.C.: 158-179

[16] Pethick, J., (1984). An Introduction to Coastal Geomorphology. Edward Arnold Publ., London, UK

[17] Savenije, H. H. G., (1992). Lagrangian Solution of St Venants Equations for Alluvial Estuary, J. Hydraul. Eng., 118, 1153–1163.

[18] Savenije, H. H. G., (1993). Determination of Estuary Parameters on Basis of Lagrangian Analysis, J. Hydraul. Eng., 119, 628–642.

[19] Savenije, H.H.G., (1998). Analytical Expression For Tidal Damping In Alluvial Estuaries. Journal of Hydraulic Engineering-Asce 124, 615{618.

[20] Savenije, H. H. G., (2001). A Simple Analytical Expression To Describe Tidal Damping Or Amplification, J. Hydrol., 243, 205–215.

[21] Savenije, H. H. G., (2005). Salinity and Tides in Alluvial Estuaries, Elsevier, New York.

[22] Savenije, H. H. G., Toffolon, M., Haas, J., and Veling, E. J. M., (2008). Analytical description of tidal dynamics in convergent estuaries, J. Geophys. Res., 113, C10025, doi:10.1029/2007JC004408.

[23] Savenije, H. H. G., (2012). Salinity and Tides in Alluvial Estuaries, completely revised 2nd Edn., www.salinityandtides.com (last access: 26 June 2013).

[24] Van Veen, J. (1950). Eb- en VIoedschaar Systemen in de Nederlandse Getijwateren. Tijdschrift Koninklijk Nederlandsch Aardrijkskundig Genootschap 67: 303-325. Annotated English translation published by Van der Spek, A., Stive, M. and Zitmans, T. (2001) Publ. Delft University.

[25] Zhang, E. F., Savenije, H. H. G., Chen, S. L., and Mao, X. H., (2012). An analytical solution for tidal propagation in the Yangtze Estuary, China, Hydrol. Earth Syst. Sci., 16, 3327–3339, doi:10.5194/hess-16-3327-2012,.

[26] Zhang, E. F., Savenije, H. H. G., Wu, H., Kong, Y. Z., and Zhu, J. R., (2011). Analytical solution for salt intrusion in the Yangtze Estuary, China, Estuar. Coast. Shelf. S., 91, 492–501.

[27] Zhang, E. F., Savenije, H. H. G., Chen, S. L., and Mao, X. H., (2012). An analytical solution for tidal propagation in the Yangtze Estuary, China, Hydrol. Earth Syst. Sci., 16, 3327–3339, doi:10.5194/hess-16-3327-2012.