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On the Response of Shallow-water Tidal Regime by Geological Characteristic of Waterway and Man-made Structures in a Macrotidal Estuary: Han River Estuary (Korea)

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ABSTRACT

Yoon, B.I. and Woo, S.-B., 2018. On the response of shallow-water tidal regime by geological characteristic of waterway and man-made structures in a macrotidal estuary: Han River estuary (Korea). *In:* Shim, J.-S.; Chun, I., and Lim, H.S. (eds.), *Proceedings from the International Coastal Symposium (ICS) 2018* (Busan, Republic of Korea). *Journal of Coastal Research*, Special Issue No. 85, pp. 16–20. Coconut Creek (Florida), ISSN 0749-0208.

To understanding shallow-water (short- and long-term period than semidiurnal tide) tidal regime in a macrotidal estuary, Han River estuary (HRE), located on the west coast of South Korea, tidal harmonic constituents of 20 stations were analysed. The semidiurnal tide dominated HRE consists of two main waterways, which have complex geological characteristics. The shallow and narrow characteristics of waterway transform propagating astronomical tides from the open-sea to shallow tidal components such as overtides and compound tides. The shallow tide (*e.g.*, M_4, MS_4, and MS_f) is important factors, which is determined water and mass circulation in a macrotidal estuary. To find shallow-water tidal regime characteristic in this study, we suggest short- and long-term period of tidal form number using shallow tidal constituents. The short-term period of tidal form number covers a range from 0.02 to 0.43, and it increase 10 times larger in the upstream estuary than the open-sea. The long-period of tidal form number is small in the open-sea, but going upward to the estuary, the value increases by 10 times, and it shows 100 times greater than that of the open-sea at the upper region of Han River. Due to complex geological characteristics of waterway, the amplitude of astronomical tidal constituent rapidly decrease and shallow water tidal constituent sharply increase. The other rapid change of tidal constituent is caused by the influence of man-made structures (Singok underwater dam) in the lower tidal river. It is apparent that regional characteristic of tidal regime caused by geological effect and influence of man-made structure.

ADDITIONAL INDEX WORDS: *Tidal regime, geological characteristic, man-made structure, macrotidal estuary*

INTRODUCTION

In an estuary system, the most distinctive characteristics compared to the open-sea are that the magnitude of the tidal range cannot be ignored in relation to the water depth and that the tides are strongly influenced by non-linear effects such as bottom friction (*e.g.*, Parker, 1991; Pugh, 1987). Because of the non-linear characteristics, the tides that display regular sine waves in the open-sea become to transformation in the tidal curve, with the magnitude and the duration times of high tide and low tide, as they propagate into the estuaries (*e.g.*, Dronkers, 1986; LeBlond, 1978). The deformations of tide and tidal current and their asymmetries can be expressed as shallow water tides which are defined by overtides and compound tides (*e.g.*, Gallo and Vinzon, 2005). Shallow water tides are a very important factor in estuarine circulation studying (Parker, 1991).

Shallow water tides are classified as overtides and compound tides depending on the astronomical tidal constituents that are combined (Le Provost, 1991). Overtides always possess frequencies that are exact multiples of the basic frequency which cause their occurrences and phase-locked wave speed (Pugh, 1987). Along with overtides generated by duplicates of identical astronomical tidal constituents, tidal constituents generated by overlaps of two different astronomical tidal constituents in shallow waters are called compound tides. Tidal asymmetries, generated by combination of various astronomical tides, are most distinct difference between the tides in estuaries and open-sea (Dronkers, 1986).

The tidal distortion has been traditionally quantified by using the amplitude ratio (H_{M_4}/H_{M_2}) to understand the magnitudes of tidal deformation and the relative phase ($2\varphi_{M_2} - \varphi_{M_4}$) of M_2 and M_4 tidal components to present the direction of tidal deformation (Aubrey and Speer, 1985; Friedrichs and Aubrey, 1988). Most papers on tidal distortion focus almost exclusively on the interaction between M_2 and M_4 as the source of asymmetry (*e.g.*, Aubrey and Speer, 1985; Friedrichs and Aubrey, 1988). These traditional methods present the following challenges; 1) the response due to combination of tidal constituents must be examined, and 2) it is difficult to make comparisons with other regions where non-linearity, accompanied by different tidal constituents (*e.g.*, S_2 and diurnal components) exist. Thus, a new methodology was proposed by Nidzieko (2010) and Song *et al.* (2011) made further improvements due to effect of another shallow water components. Therefore, it is important to

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understanding both overtides and compound tides in the estuary where S_2 component is dominant as well as M_2 component.

The objective of this study is to present the characteristics of tidal propagation, which included astronomical tides, overtides, and compound tides where the geographical characteristics of each channels are distinctive. In addition, this study has made regional classifications of tidal regime by using the traditional tidal form numbers, along with traditional parameter and modified parameter and of tidal distortion, which include compound tides (*e.g.*, MS_4 and MS_f) effects.

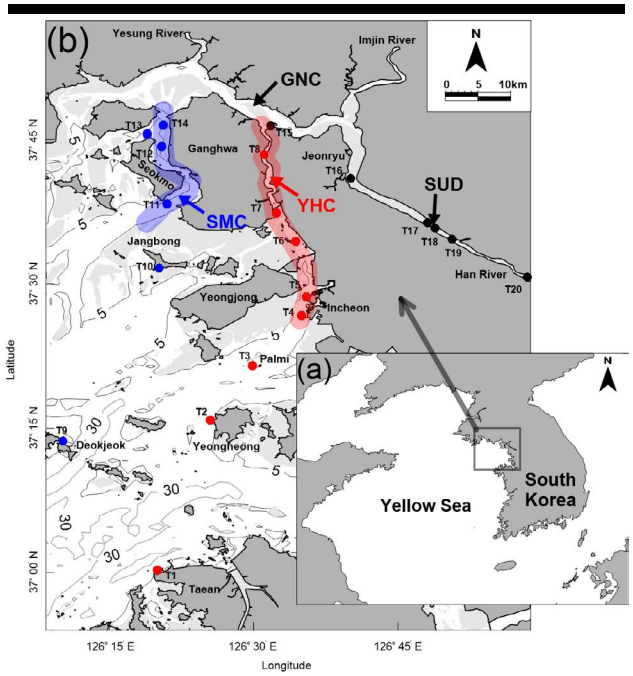


Figure 1. (a) Map showing for midwestern and southwestern coastal zones of South Korea. (b) Bathymetric and tidal station of Gyeonggi Bay (GGB) with 5 m (thin black line) and 30 m (gray line) isobaths. The observation points for tide (T1-T20, red, blue, and black circles) is shown around GGB. The shaded areas (light gray) indicate intertidal flats. The main channel of study area is Yeomha Channel (YHC, red line), Seokmo Channel (SMC, blue line), and Ganghwa north Channel (GNC). The Singok underwater dam (SUD) is located between T17 and T18 observation point.

METHODS

Tide Data

To analyze quantification tidal characteristic of research area, tide data from total 20 points, such as 6 point in the open-sea (T1-T5 and T9), 4 points in the eastern side of Ganghwa (T6-T8 and T15), 5 points in the western side of Ganghwado (T10-T14), and 5 points in the upstream estuary (T16-T20), were collected (Figure 1b). That is provided by Korea Hydrographic and Oceanographic Administration (KHOA), Han River Flood Control Office (HRFCO). The tide points through YHC are presented Taesan (T1), Yeongheung (T2), Palmi (T3), the Incheon Harbor (T4 and T5), Seo (T6) and the Ganghwa Bridge (T8). The tide stations through SMC are showed Deokjeok (T9), Jangbong (T10), Seokmo (T11 and T12), and north entrance of channel (T14). There are tide points such as Jeonryu (T16), downstream of SUD (T17), and upstream of SUD (T18-T20) in upstream area of Han River estuary (HRE). Since the region around Ganghwa north Channel (GNC) is the borderline between South Korea and North Korea, access to the around GNC is limited and so are filed data (Park *et al.*, 2002). Excluding the GNC, there are enough data for considering overall tidal propagation from open-sea of GGB to upstream region of HRE.

Tidal Form Number by Methodology

To estimate influence of overtides and compound tides, shallow water tidal form numbers (F_{FD}, (1) and F_{LP}, (2)) were suggested. The shallow water tidal form numbers were divided into shorter and longer components than the period of 4 major tidal constituents. The short period of shallow water tidal form numbers (*i.e.*, fourth-diurnal tidal form number, F_{FD} in (1)) consist of overtides (M_4) and compound tides (MS_4) and long period of shallow water tidal form numbers (*i.e.*, long-term period tidal form number) are calculated using overtides (Mm) and compound tides (MS_f). Sum of F_{FD} and F_{LP} is total shallow water tidal form numbers (F_{Tot}, (3)).

$$F_{FD} = \left(H_{M_4} + H_{MS_4}\right)/\left(H_{M_2} + H_{S_2}\right) \quad (1)$$

$$F_{LP} = \left(H_{MS_f} + H_{M_M}\right)/\left(H_{M_2} + H_{S_2}\right) \quad (2)$$

$$F_{Tot} = \left(H_{M_4} + H_{MS_4} + H_{MS_f} + H_{M_M}\right)/\left(H_{M_2} + H_{S_2}\right) \quad (3)$$

RESULTS

Tidal Propagation Characteristic

The tidal harmonic constants for the 20 points (T1-T20 refer to Figure 1) presented in the following categories; long-term period (M_m and MS_f), diurnal (O_1 and K_1), semi-diurnal (M_2, S_2, and N_2) and fourth-diurnal (M_4 and MS_4) tidal constituents. The amplitude of semi-diurnal tides (*e.g.*, M_2) gradually increases towards to up-estuary from the open-sea and sharply decreases beyond certain point (Figures 2a, 3a). The sharply decreasing point of amplitude variation of semi-diurnal tides show as they propagate into YHC at the south entrance (T7) and as they propagate into SMC at the north entrance (T14). The amplitude of diurnal tides components (*e.g.*, K_1) is one order of magnitude smaller than M_2 and appear to vary in similar pattern such as the semi-diurnal tides. Although, other tidal constituents (S_2, N_2, and O_1) are not shown, they display similar pattern as they propagate to the upstream.

Unlike the variations of semi-diurnal and diurnal tide constituent, the shallow water tidal constituent (*e.g.*, M_4) does not show large changes in the points that are relatively near the open-sea, however shows sharply increasing as it propagates into the up-estuary (Figures 2b, 3b). Shallow water tidal constituent appears increases of more than 20 cm beyond the south entrance of YHC (T7) and beyond the north entrance of SMC (T14). The maximum shallow water tidal constituents appear in the T15 point, where the junction of two channels (YHC and SMC). MS_4 tidal constituent, another shallow water tidal constituent, is not shown because similar form as M_4 and the location of the maximum amplitude.

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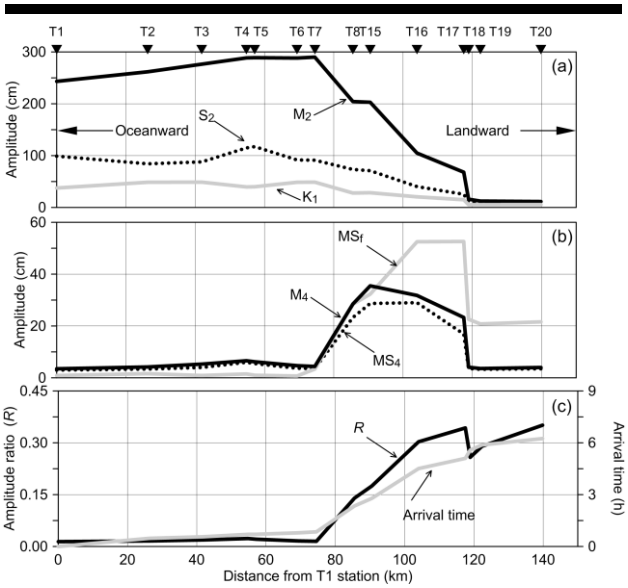


Figure 2. (a) A change of amplitude of semi-diurnal (M_2; black line and S_2; black dotted line) and diurnal (K_1; gray line) constituents. (b) A change of amplitude of fourth-diurnal (M_4; black line and MS_4; black dotted line) and long-term period (MS_f; gray line) constituents. (c) Amplitude ratio ($R = H_{M_4}/H_{M_2}$; black line) and arrival time (gray line) of tide based on phase of M_2 constituent of water level (Warner, Schoellhamer and Schladow, 2003) along the YHC. Tidal constituent stations (reverse triangles) are marked along the distance in the top of figure.

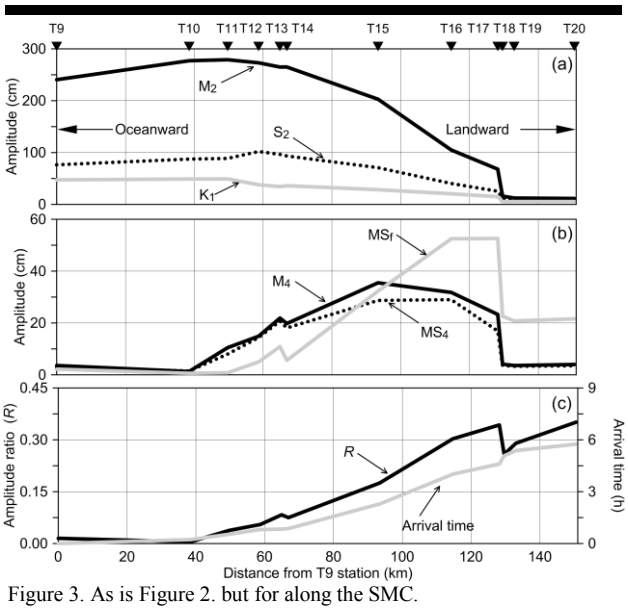


Figure 3. As is Figure 2. but for along the SMC.

A long-term period tidal constituent (*e.g.*, MS_f) shows similar pattern as the shallow water tidal constituent as it propagates the upstream, however T17 and T18 points near SUD (Singok underwater dam) of maximum amplitude occur in further upstream compared to those of the shallow water tidal constituent (Figures 2b, 3b). The long-term period tidal constituent has its maximum at a point approximately 32 km upstream that of the shallow water tidal constituent. The long-term period tidal constituent, which shows almost constant variation of magnitude between T16 to T17, shows a sharply decreasing beyond T17 and then shows a constant magnitude again until the T20 point. M_m tidal constituent, another long-term period tidal constituent, also shows a similar pattern and the location of the maximum value was not shown because they are identical.

DISCUSSION

Fourth-diurnal and Long-term Period Tidal Form Number

The results, such as calculation of tidal propagation time by phase and asymmetry (H_{M_4}/H_{M_2}), were obtained mainly using M2 tidal constituent, the largest constituent of semi-diurnal tides, and overtides (M_4) by M_2 tidal constituent. As shown in previous results, the next largest tidal constituent after M_2 is S_2 tidal constituent. It is necessary to produce the occurrences and characteristics of compound tide constituents created by the combination of these two tidal constituents.

We examine a known mechanism, namely a non-linear bottom frictional combination of the M_2 and S_2 tidal constituents. If shallow water effects are proportional to the square of the tidal water level through a spring-neap period, four harmonic constituents can be generated (Pugh, 1987), as followed:

$$\begin{aligned}\left\{H_{M_2}cos2\omega_1 t + H_{S_2}cos2\omega_0 t\right\}^2 &= \left\{\frac{1}{2}\left(H_{M_2}^2 + S_{S_2}^2\right)\right. \\ &+ \frac{1}{2}\left(H_{M_2}\right)^2 cos4\omega_1 t \\ &+ \frac{1}{2}\left(H_{S_2}\right)^2 cos4\omega_0 t \\ &+ H_{M_2}H_{S_2}cos2(\omega_1+\omega_0)t \\ &\left.+ H_{M_2}H_{S_2}cos2(\omega_0-\omega_1)t\right\}\end{aligned} \quad (4)$$

where, H is the water levels of M_2 and S_2, ω_0 and ω_1 are angular speed (radians) of M_2 and S_2 respectively, and t is the time. The first to third term on the right side of (4) means M_4, S_4 and MS_4, which shows fourth-diurnal components, and the angular speed are $4\omega_1$, $4\omega_0$ and $2(\omega_1+\omega_0)$, respectively. Long-term period tidal constituents are also produced. The tidal constituent which shows an angular speed of $2(\omega_0-\omega_1)$ produced by the difference between the two tidal constituents are defined by MS_f and the tidal cycle is 14.78 day. MS_f tidal constituent displays a cycle that is identical to the changes of spring–neap tides. In addition, MS_f sometimes produces changes in the mean sea level through $H_{M_2}^2 + S_{S_2}^2$.

Although the overtides, which is produced by the composition of M_2 tidal constituent, have the most prevalent influence on typical estuarine system, the compound tides produced by the composition of M_2 and S_2 cannot be ignored since the S_2 tidal constituent is not small in our study area. Therefore, it is necessary to consider the compound tides produced not only the amplitude of M_4 but also by the composition of M_2 and S_2 in this study. To understand this, the shallow water tidal form number

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(F_{FD}, F_{LP}, and F_{Tot}), which are adjusted to be like the tidal form numbers, are defined as (1), (2) and (3).

F, F_{FD}, and F_{LP} show changes as they enter the upstream of estuary through T1 (YHC) and T9 (SMC) from the open-sea (Figure 4). Typical F shows variance range of 0.2–0.3 until 120 km point and rapidly increases beyond that point as it passes by SUD. Overall trend, however, is dominant semi-diurnal ($F < 0.25$) or mixed semi-diurnal ($0.25 < F < 1.5$). The reason for a rapid increase beyond SUD (T17) is because the decreasing of diurnal tides is relatively small while both semi-diurnal tides and diurnal tides show decreases. The variation of F_{FD} is larger than the R, however, their trends are similar. But, F_{LP} which is the variance of long-term period tidal constituent, continues to increase until the 120 km point, just like the case of F_{FD}, but then increases rapidly beyond that point unlike F_{FD}. F_{LP} also, rapidly increases like the F value. This is because the semi-diurnal tide which is a relatively a short period constituent and the fourth-diurnal tidal constituent are less strongly influenced by the bottom friction than the diurnal tides or long period constituents and therefore the range of decrease is small (*e.g.*, Winant, 2007).

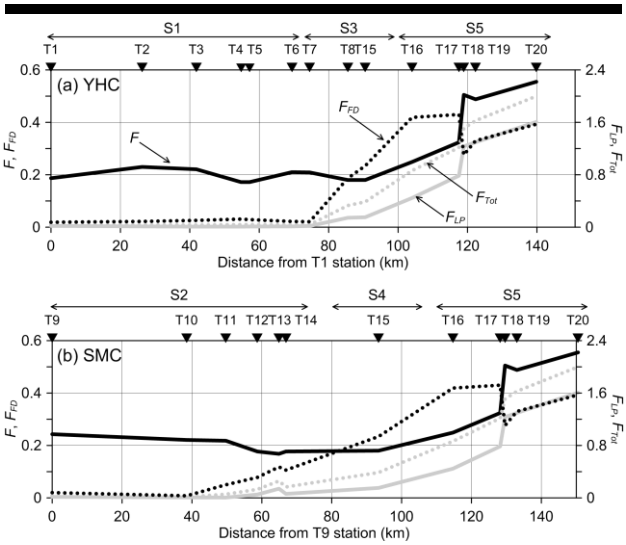


Figure 4. The variation of tidal form number (F; black solid line), fourth-diurnal tidal form number (F_{FD}; black dotted line), and long-term period tidal form number (F_{LP}; gray solid line) along the (a) YHC and (b) SMC. Tidal constituent stations (reverse triangles) and regional classifications of tidal regime (double arrows) are marked along the distance in the top of figures.

Influence of Man-made Structure

Singok underwater dam (SUD) built in 1987 for a purpose of water level management for transportation of ships, irrigation water management, and prevention of salinity water intrusion (Baek and Yim, 2011). The height of SUD is 2.7 m (altitude from sea-bottom: E.L. 2.4 m + spillway height: 0.3 m). Tidal wave propagates to the upstream over the underwater dam only when the tidal water propagated from the open-sea is over 2.7m. Because of the height of the underwater dam, the tide phenomenon in the upstream of SUD occurs during spring tide (Chang and Oh, 1991). In other words, SUD block the most tides that have smaller tidal ranges, but the tides during periods where the tidal rages are big will have influence on the tides in the upstream of SUD. Most of such tides propagated beyond SUD will be blocked at the Jamsil underwater dam (E.L. 6.2 m) 31 km upstream from SUD (Yoon and Woo, 2013).

A tidal time series, observed before (in 1985) and after (in 2008) the construction of SUD, shows significant difference of water levels (Figure 5). The water level of the two periods have similar freshwater discharge condition (under 400 m^3s^{-1}) and the tidal cycles. The water level in 1985 has a noticeable variation of spring–neap tides and diurnal inequalities. On the other hand, the water level in 2008 shows that tidal change is not noticeable during neap tides (*e.g.*, June 13) and that we can see some increasing and decreasing only during spring tides (*e.g.*, June 5). Additionally, the mean sea-level maintain an almost constant level (2.0 m) due to the influence of the SUD in 2008. Due to a development of tidal water level only during spring period after construction of SUD (*e.g.*, in 2008), MSf tidal components is dominated at the upstream regions of SUD.

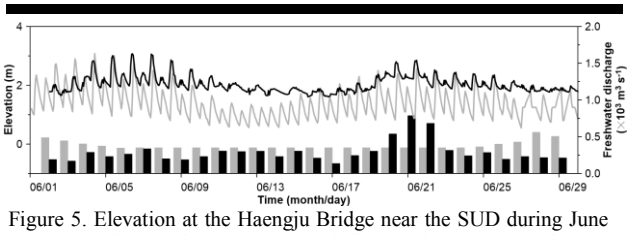


Figure 5. Elevation at the Haengju Bridge near the SUD during June 1985 (gray line) and June 2008 (black line) under normal freshwater discharge condition. Gray (year 1985) and black bar (year 2008) chart indicate freshwater discharge rate refer to Paldang dam (60 km upstream from SUD).

CONCLUSIONS

The semi-dinunal dominated HRE was classified into 3 zones in accordance with the characteristics of tidal regimes such as fourth-diurnal and long-term period tidal form number which was obtained by using astronomical tides, overtides, and compound tides and amplitude ratio (H_{M_4}/H_{M_2}). First regions with the dominance of astronomical tides are from the open-sea to the front of Incheon Harbor and from the open-sea to the north entrance of Seokmo Channel. The regions from the south entrance of Yeomha Channel to its north entrance and the Ganghwa North Channel can be classified as regions where the fourth-diurnal shallow water tides are predominant. The regions beyond Singok underwater dam and the upstream beyond the underwater dam can be classified as regions where amplitude of the shallow water overtides (*e.g.*, M_4) and long-term period compound tides (*e.g.*, MS_f) are larger than those of the astronomical tides. The tidal non-linearity of the upstream regions is caused by man-made structures like an underwater dam.

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LITERATURE CITED

Aubrey, D.G. and Speer, P.E., 1985. A study of non-linear tidal propagation in shallow inlet/estuarine systems, part I: observations. *Journal of Estuarine, Coastal and Shelf Science*, 21(2), 185–205.

Baek, K.O. and Yim, D.H., 2011. Flow Characteristics Induced by Shift and Modification of Submerged Weir at Han River Estuary. *KSCE Journal of Civil Engineering*, 28, 109–119.

Chang, H.D. and Oh, J.K., 1991. Depositional sedimentary environments in the Han River estuary and around the Kyunggi Bay posterior to the Han River's development. *Journal of the Korean Society of Oceanography*, 26, 13-23.

Dronkers, J., 1986., Tidal asymmetry and estuarine morphology. *Netherlands Journal of Sea Research*, 20(2/3), 117–131.

Friedrichs, C.T. and Aubrey, D.G., 1988. Non-linear tidal distortion in shallow well-mixed estuaries: a synthesis. *Journal of Estuarine, Coastal and Shelf Science*, 21, 185–205.

Gallo, M.N. and Vinzon, S.B., 2005. Generation of overtides and compound tides in Amazon estuary. *Ocean Dynamics*, 55, 441–448.

Le Provost, C., 1991. Generation of overtides and compound tides (review). *In*: Parker, B.B. (ed.), *Tidal hydrodynamics*. NewYork: J. Wiley and Sons, pp. 269–295.

LeBlond, P.H., 1978. On tidal propagation in shallow rivers. *Journal of Geophysical Research*, 83, 4717–4721.

Niedziko, N.J., 2010. Tidal asymmetry in estuaries with mixed semidiurnal/diurnal tides. *Journal of Geophysical Research*, 115, C08006, doi: 10.1029/2009JC005864.

Park, K.; Oh, J.-H.; Kim, H.-S., and Im, H.-H., 2002. Case study: Mass transport mechanism in Kyunggi Bay around Han River mouth. *Journal of Hydraulic Engineering*, 128, 257-267.

Parker, B.B., 1991. The relative importance of the various nonlinear mechanisms in a wide range of tidal interactions (review). *In*: Parker, B.B. (ed.), *Tidal Hydrodynamics*. New York: J. Wiley and Sons, pp. 237–268.

Pugh, D.T., 1987. *Tides, Surges, and Mean Sea-Level*. Chichester, U.K.: J. Wiley and Sons, 486p.

Song, D.; Wang, X.H.; Kiss, A.E., and Bao, X., 2011. The contribution to tidal asymmetry by different combinations of tidal constituents. *Journal of Geophysical Research*, 116, C12007, doi: 10.1029/ 2011JC007270.

Warner, J.C.; Schoellhamer, D. and Schladow, G., 2003. Tidal truncation and barotropic convergence in a channel network tidally driven from opposing entrances. *Estuarine Coastal Shelf Science*, 56, 629–639.

Winant, C.D., 2007. Three-dimensional tidal flow in an elongated, rotating basin, *Journal of Physical Oceanography*, 37, 2345-2362, doi:10.1175/JPO3122.1.

Yoon, B.I. and Woo, S.-B., 2013. Tidal asymmetry and flood/ebb dominance around the Yeomha channel in the Han River Estuary, South Korea. *In*: Conley, D.C.; Masselink, G.; Russell, P.E., and O'Hare, T.J. (eds.), *Proceedings, 12th International Coastal Symposium. Journal of Coastal Research*, Special Issue No. 65, pp. 1242-1246.

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