Numerical Simulation of Tidal Currents around Korea/Japan Strait and Application to Speed Trial

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***Abstract*-The speed performance of a vessel is a very important factor for shipbuilding companies and its owners, because the operating costs and time will increase, if the vessel could not qualify the contracted speed. Therefore, in the last phase of construction of a vessel, a shipbuilding company will perform a sea trial to measure the vessel's speed performance. Korean shipbuilding companies sometimes have carried out the sea trials around the western channel of Korea/Japan strait, where the flow fields are very complicated due to the effect of various flows. Because the interference by these flows to a ship seems to be significantly high, the numerical reproduction of the flow-fields in the vicinity of the target sites can help better understanding the sea environments and performing the sea trials. In this study, we used the MEC ocean model to simulate the tidal currents around Tsushima Island and compared the simulated tidal amplitudes and currents with those of measurements by W.J. Teague. The tidal amplitudes of present simulation results agree well with the observations. Based on the numerical simulation, the optimal direction and proper sites for a speed trial were described.**

I. INTRODUCTION

In the last phase of construction of a vessel, sea trials are conducted to measure a vessel's performance and general seaworthiness, such as a vessel's speed, maneuverability, equipment and safety features and so forth. Successful sea trials subsequently lead to a vessel's certification for commissioning and acceptance by its owner. However, on the contrary, if some of them do not reach the target, generally written in the contract between a ship-building company and a ship owner, the ship-building company should pay a fine and, furtherer at worst, the ship owner can cancel the contract.

The speed performance of a vessel is a very important one for shipbuilding companies and its owners, because the operating costs and time will increase, if the vessel could not qualify the contracted speed.

The speed of a newly manufactured vessel is generally predicted by model tests, such as resistance and propulsion tests, in a ship basin and this predicted speed is guaranteed at the Beaufort (scale) number 0, which corresponds to the state of the calm sea when there is no wind, breaker or tidal wave [1].

However, the speed trial of a vessel is performed with wind on the sea, where the flow fields are complicated due to the effect of various flows, such as oceanic current, tidal current, geo-strophic current, wind-driven current and so forth [2]. These sea-flows make it hard for the vessels to enter and leave the port. Also, they make it hard to predict the floating objects' movements. In case of an accident, such as leakage of oil, there is no time for response.

As mentioned, the guaranteed speed of a vessel is estimated under the assumption that there are no external influences, such as wind and flows in the trial area. However, when carrying out the real speed trial on the sea, we cannot expect such an ideal status. Because the interference by various currents to a ship seems to be significantly high, the numerical reproduction of the flow fields in the vicinity of the sites of speed trials can help better understanding the sea environments and performing the sea trials. Regarding the tidal currents, the velocity and direction continuously change spatially and temporally. As a result, it is not easy to measure the speed of the vessel using the results of the simulated trial operation for speed.

Korean shipbuilding companies sometimes have carried out the sea trials around the western channel of Korea/Japan strait. According to the statistical data for the sea state around this area, the averaged annual tidal height is 1 to 1.5 meters, which are typically observed in the sea state of Beaufort number 3 [3]. Therefore, one can easily imagine that there would be a big difference from the sea state of Beaufort number 0, the

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idealistic state of waters where the trial operation is carried out. Also, it is possible to estimate the errors for revising the results. If the tidal currents around Tsushima where the trial operation is carried can be predicted, it would help performing the trial operation for the effective speed there.

According to [4], the RIAM model was used to carry out the numerical simulation for the sea-flow around Tsushima Island. The values observed with the Acoustic Doppler Current Profiler (ADCP), which had been installed on a passenger ship for six months, and the velocities and directions of the tidal currents measured in the upper part of Tsushima Island were compared and studied. Also, according to [5], sea-flows had been observed by 11 ADCPs for six months in the Korea/Japan strait.

Through the analysis of such preceding researches, the characteristics within the Korea/Japan strait could be summarized as follows.

The sea-flows in the Korea/Japan strait can be characterized by the two-way tidal currents made of the flood tidal current in the northeast direction and the ebb tidal current in the southwest direction, and the Tsushima ocean current, which flows in the northeast direction with the velocity of 30-80 cm/s. Generally, the seawater around Seosu Island is stronger in summer than in winter. However, the seawater passing through Dongsu Island shows no specific seasonal changes. Also, the strength of the seawater within the Korea/Japan strait is not constant, showing that the velocity of the sea-flows around Seosu Island is much higher than that around Dongsu Island [6].

However, it is difficult to apply the preceding researches, because the target area of the observations and simulations are different from that in this research. Therefore, the numerical simulation of the flow-fields in the target was carried out to predict the temporal changes of the sea-flows, mainly focusing on the tidal amplitudes, at some specific locations together with the spatial distribution of the sea-flows, which are thought to be useful to decide the optimal direction and proper sites for speed trials in the target are at specific time.

In this paper, after reviewing the computational results, the methods of utilizing the results for the speed trials are discussed.

II. NUMERICAL MODEL

A. MEC Ocean Model

In this study, MEC (Marine Environmental Committee) Ocean model, which was developed by Marine Environmental Committee of the Japan Society of Naval Architects and Ocean Engineers, was used for the numerical simulation of ocean currents around the western channel of Korea/Japan strait including Tsushima Island. The MEC ocean model is a hybrid numerical one, which can harmoniously couple the simulation region of the hydrostatic-approximated flows with those of the full three dimensional ones [7].

B. Governing Equation

The governing equations for the simulation of this study are the equation of continuity (Eq. 1) and the hydrostatic approximated Navier-Stokes equation including the Coriolis force (Eq. 2~Eq. 4).

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \tag{1}$$

$$\begin{aligned}&\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\\&-\frac{1}{\rho}\frac{\partial p_s}{\partial x}+fv+A_M\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial u}{\partial z}\right)\end{aligned} \tag{2}$$

$$\begin{aligned}&\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=\\&-\frac{1}{\rho}\frac{\partial p_s}{\partial y}+fv+A_M\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{\partial}{\partial z}\left(K_M\frac{\partial v}{\partial z}\right)\end{aligned} \tag{3}$$

$$0=-\frac{1}{\rho}\frac{\partial p}{\partial z}-\mathrm{g} \tag{4}$$

where, u, v, w, t, p_s, f and g are the velocity components along x, y and z directions in the Cartesian coordinate system, time, hydrostatic pressure, the Coriolis parameter, and gravitational acceleration. A_M and K_M denote the horizontal and vertical eddy viscosities, respectively.

The density of seawater is assumed to be a function of temperature T and salinity S, and the equation is presented as below,

$$\begin{aligned}\rho=&1028.14-0.073T-0.00469T^2\\&+(0.802-0.002T)(S-35.0)\end{aligned} \tag{5}$$

III. NUMERICAL SIMULATION

A. Simulation Area

The target area, where Korean shipbuilding companies have frequently carried out speed trials, is shown as a square drawn by dotted lines in Fig. 1. The one-minute grid data of National Oceanographic Research Institute in 2007 were collected and 3rd-order spline was adopted to interpolate the topography for a target site with the resolution of 30-second.

B. Simulation Conditions

The dimensions of the computational domain were approximately 230 x 230 x 0.2 (km) in the x, y, z directions, respectively. Although the numbers of the grids in the x, y directions were fixed as 201 with the uniform grid-spacing of 1142.37 m, the ones in the vertical direction were varied (set as 10, 20, 30 and 40) to investigate the influence on the computational result due to the change of the grid-size in the vertical direction.

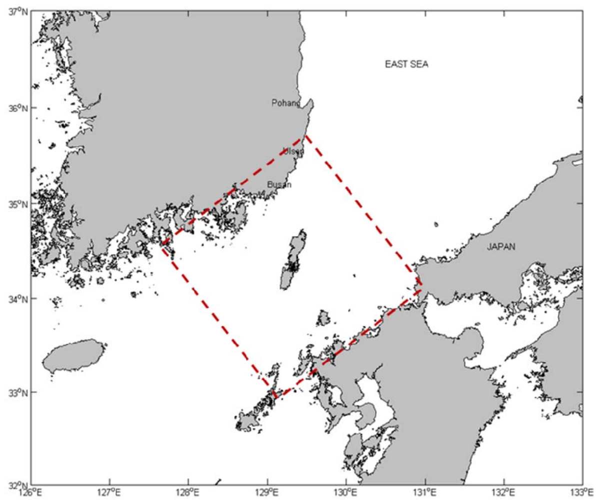

Figure 1. Simulation area around Tsushima Island.

To coincide with the direction of dominant tidal current in the target area, the grid system was rotated by 36° in the counter-clockwise direction. The time interval for the simulation was set to be three seconds.

The north and south sides of the computational domain were treated as closed boundaries. The boundary conditions imposed at these boundaries were zero normal velocity condition and no slip condition. At the open boundaries, say, the west and east boundaries, sea level was compulsory given by the harmonic constants of 4 major tidal currents, M2, S2, O1 and K1, and the gradient of the current velocities in normal direction was taken to be zero. Tidal information was obtained from the Japanese NAO99JB model [8], which is known to provide the most accurate harmonic constants around the Korean Peninsula [2]. To acquire the values at the specific locations of the open boundaries, 3rd-order spline interpolation was used. The spatial size and the number of grids are listed in Table 1 with the parameters necessary for the simulation.

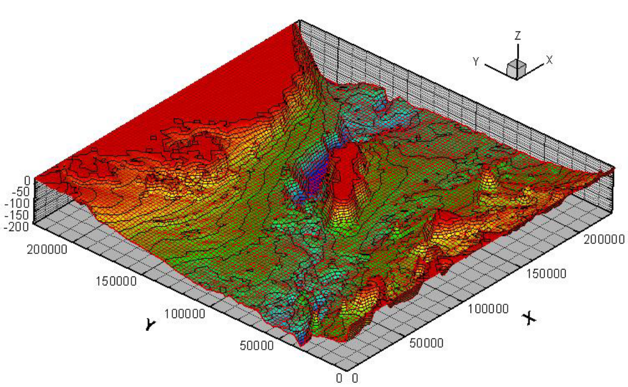

Figure 2. Bathymetry and computational domain of Korea/Japan strait.

TABLE I VALUES OF PARAMETERS USED IN SIMULATION

Numbers of grids in the x, y, z directions	201 × 201 x 10, 20, 30, 40
Horizontal grid size (m)	1142.37
Horizontal eddy viscosity (m^2/s)	20
Vertical eddy viscosity (m^2/s)	0.0001
Horizontal eddy diffusivity (m^2/s)	20
Vertical eddy diffusivity (m^2/s)	0.0001
Time interval (s)	3
Water density (kg/m^3)	1025
Frictional coeff. at sea bottom	0.0025
Frictional coeff. at sea surface	0.0013

IV. RESULTS OF SIMULATION

In order to check the accuracy of present simulation, the simulated tidal amplitudes at four points of the southern part and four points of the northern part of Tsushima Island were compared with those of measurements. The filled circles in Fig. 3 indicate the positions for the comparison.

Fig. 4 shows the comparisons of the temporal changes of the tidal amplitudes of measurements with those of simulations at the comparison points. The present simulation results agree well with the experiments. It means that the tidal environments around the target site can numerically reproduced well and the numerical prediction can apply to the sea trials. And, the influences due to the change of the grid size in the vertical direction on the computational were trivial and we chose 20 as the number of grids in the vertical direction.

The temporal changes of the velocity vectors at the ST-1 and ST-2 are shown in Fig. 5.

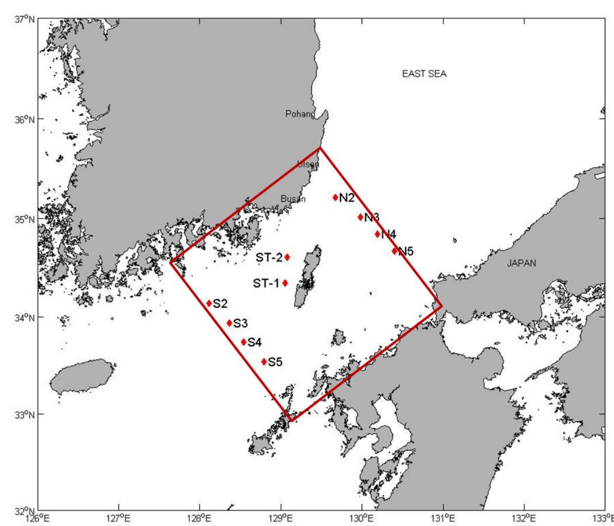

Figure 3. Selected positions to monitor the simulated tidal amplitudes.

V. APPLICATION METHODS FOR SPEED TRIAL

As explained in chapter I, when carrying out the speed trial of a vessel, it is necessary to make the external influences as small as possible and to perform it in the constant state where the velocities and directions of the tidal and the sea currents are constant and stable.

Therefore, if the characteristics of the sea-flows in the target area could be predicted and identified in advance, it can be possible to carry out the speed trial in the most stable status. In other words, it is necessary to choose the area where the temporal and spatial changes of tidal currents are small along the line of the running of a vessel for the speed trial.

Fig. 6 shows the statistical results of the direction of the tidal current and the distribution of the tidal waves around Tsushima Island. The maximum velocity of the tidal currents around Tsushima is less than 1m/s and the directions of them are between 25°~30° and 180°~210° as depicted in the Fig. 6(A). Fig. 6(B) indicates that the degrees of the frequently occurred tidal currents are in the range between 180° and 210°. Therefore, when carrying out the speed trial around Tsushima Island, it is expected to become most efficient when carrying it out along the direction between 25°~30° and 180°~210°.

Fig. 7 shows the instantaneous velocity vector fields around Tsushima Island. When carrying out the speed trial, it is better to avoid the period of time, when the influences caused by the direction of the tidal current are predicted, such as (A) and (B) in Fig. 7. When the flow-fields are in the status like (C), there is a possibility for the ship to receive the sided tidal current in the southern part of Tsushima Island. In this case, if there is a flow of the tidal current, its direction is similar to that of the trial operation, in the northern part of Tsushima Island, it is better to carry out there. On the contrary, in the case of (D), it can be thought that to carry out the speed trial in the southern part of Tsushima Island is better.

Also, it is beneficial to make the vessel to run along the main direction of tidal currents before they change their direction. In other words, it is necessary to avoid the time, when the direction of the tidal current changes rapidly, like (A) in Fig. 8, since there is a possibility for the ship to get the influence of the sided tidal currents during its running. The suggested optimum time and direction for the speed trial are depicted in Fig. 8(B).

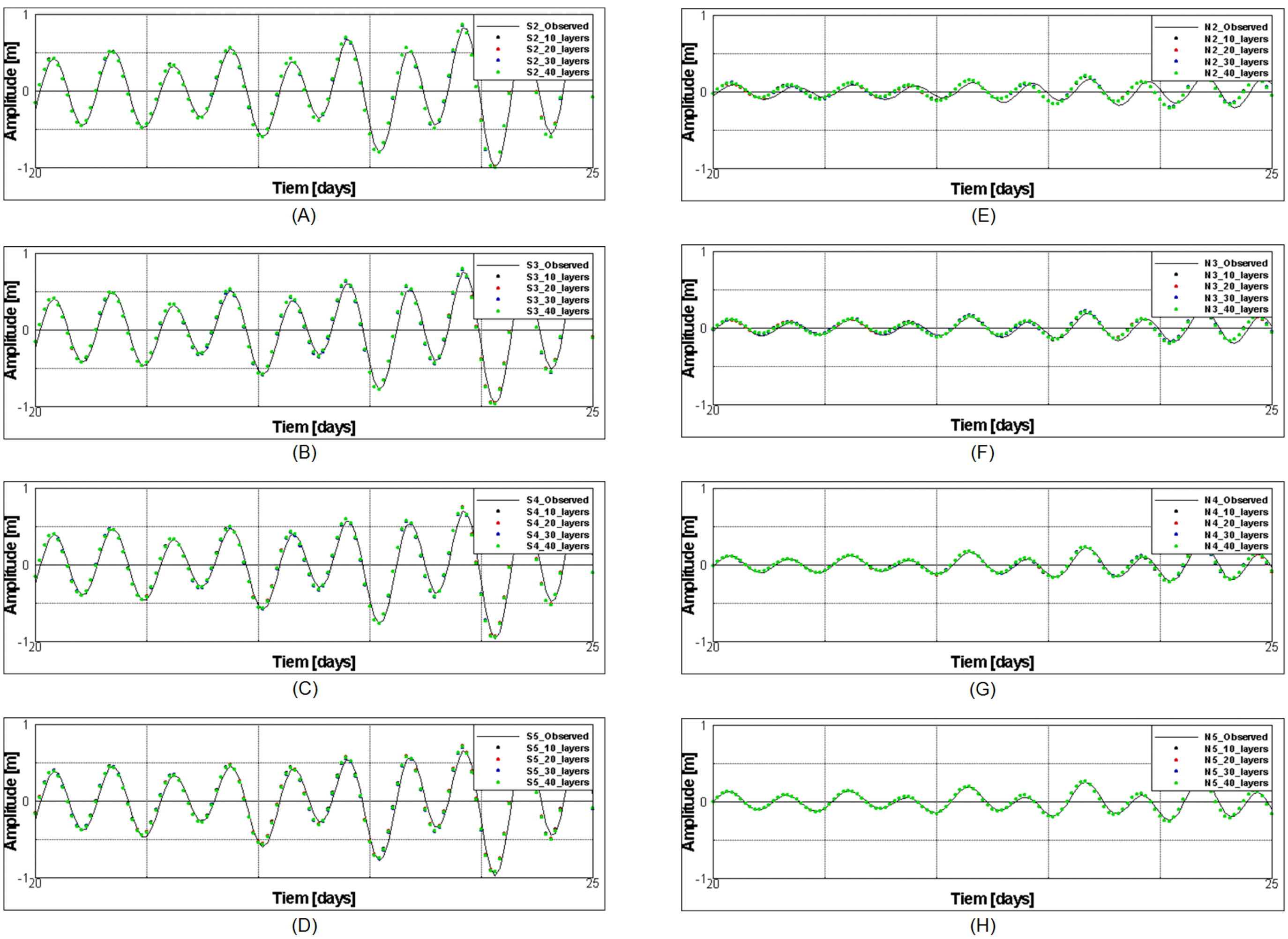

Figure 4. Comparison of amplitude of tide between observation and simulation; at (A) S2, (B) S3, (C) S4, (D) S5, (E) N2, (F) N3, (G)N4, (H) N5.

VI. Conclusion

In this study, MEC (Marine Environmental Committee) ocean model developed by the Japan Society of Naval Architects and Ocean Engineers was used for the numerical simulation of the flow-fields around the western channel of Korea/Japan strait including Tsushima Island to predict the temporal changes of the sea-flows, mainly focusing on the tidal currents, at some specific locations together with the spatial distribution of them, which are thought to be useful to decide the optimal direction and proper sites for speed trials in the target are at specific time.

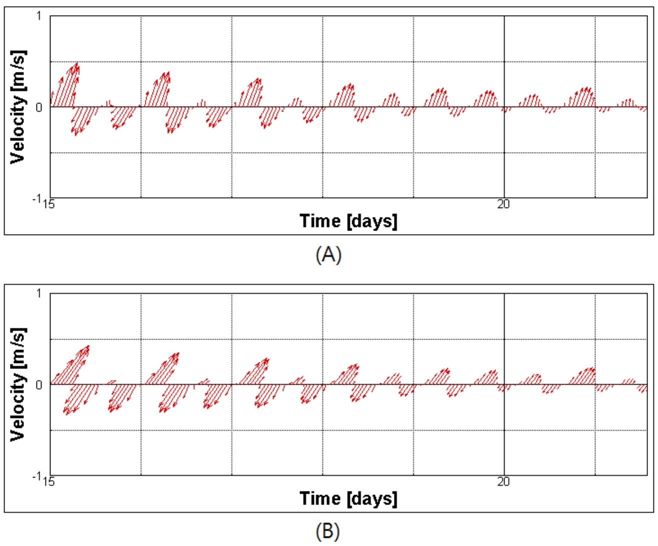

Figure 5. Velocity vector diagrams at ST-1 (A) and ST-2 (B).

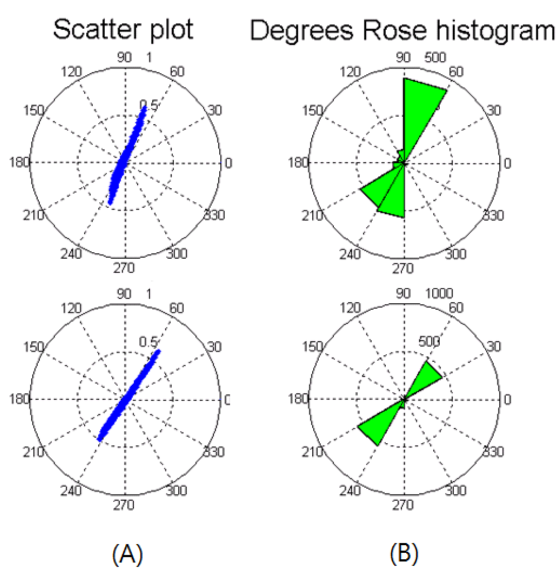

Figure 6. Velocity and direction distribution of tidal current around Tsushima Island; Scatter plot of tidal current direction and velocity (A) and Rose histogram of tidal current degrees at (upper) ST-1 and (lower) ST-2 (B).

The present simulation results agree well with the experiments. It means the tidal environments around the target sites can numerically reproduced well and the numerical prediction can apply to the sea trials.

Based on the numerical simulation, the optimal running time, direction and proper sites for the speed trial, were suggested

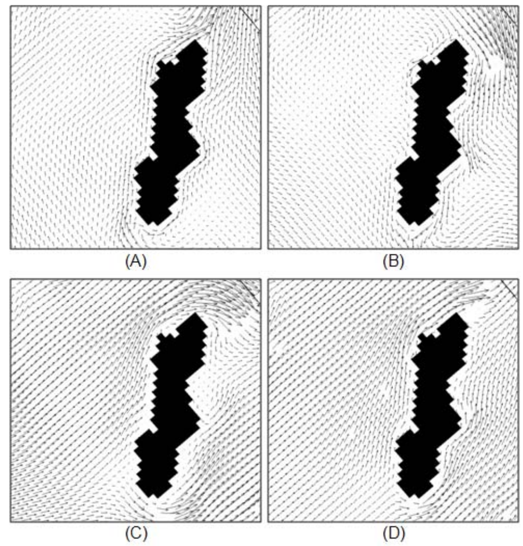

Figure 7. Velocity vector fields around Tsushima Island at ebb tides (A), (B) and flood tides (C), (D).

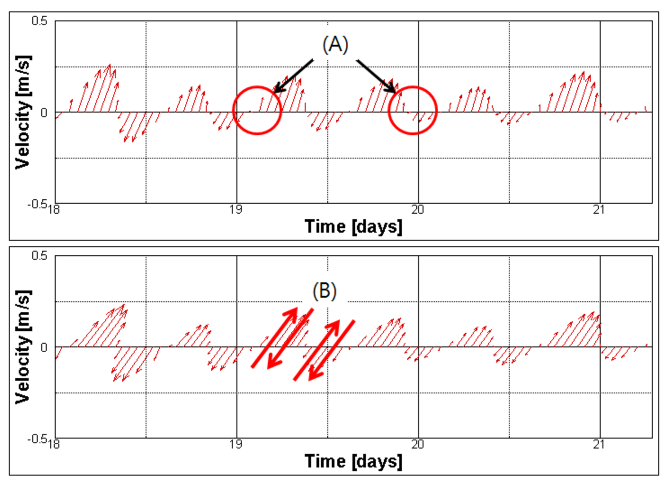

Figure 8. Running order for the speed trial considering current velocity; (A) Time at the direction of tidal current is changing, (B) Running order.

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