Bed instability generated by turbidity currents

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A turbidity current is a density flow that increases its density more than surrounding water by entraining fine sediment on the bed, and flows down the surface of the ocean floor. A turbidity current plays an indispensable role in the generation of petroleum and methane hydrate, which is to transport organic matters originated from land areas deposited on continental shelves to the deep ocean floor. In addition, a turbidity current is the main agent which forms the submarine geomorphology such as submarine canyons, submarine fans, and submarine rivers by the strong abilities for erosion and sediment transport. In this study, a linear stability analysis is performed to explain the formation of boundary waves with a regular wavy shape in the flow direction in the submarine geomorphology due to turbidity currents.

In the cases of saline and thermal density flows, they cannot travel long distances because the difference of salinity or temperature between the surrounding water and itself as a driving force decreases by diffusion as it travels. In turbidity currents however, there is an equilibrium state of the high-concentration layer below the density interface which does not change the flow velocity or the layer thickness in the streamwise direction because the diffusion of suspended sediment upward is balanced with the settling downward. Therefore, turbidity currents can travel very long distances (Luchi et al. 2015, Luchi et al. 2018). Then, by imposing small sinusoidal disturbances on the flat bed base state condition formed by the equilibrium state, the formative conditions of the boundary waves are studied in terms of linear stability analysis.

In the analysis, we employ the Reynolds-averaged Navier-Stokes equations and the advection/diffusion equation of suspended sediment including Boussinesq’s eddy viscosity. A standard k-epsilon model is adopted as a turbulent closure scheme, in which the eddy viscosity is expressed by the combination of the turbulent kinetic energy and the dissipation rate. In the process of normalization, there appear two important non-dimensional parameters: the settling velocity of sediment normalized by the friction velocity, and the Richardson number (or density Froude number).

In the equilibrium base state, the flow velocity and the suspended sediment concentration do not change in the streamwise direction, and the flow velocity in the direction of the layer thickness vanishes. Therefore, in the governing equations in the base state, the flow velocity, the suspended sediment concentration, the turbulent kinetic energy, and the dissipation rate appear as functions only of the coordinate in the layer thickness direction. A numerical calculation scheme with the use of the finite volume method is used to obtain the distributions of velocity and suspended sediment concentration. Compared between the results with and without the effect of density stratification, it is found that the density stratification suppresses turbulent diffusion, and emphasizes the differences of the flow velocity and the suspended sediment concentration between the vicinities of the bed and the density interface. As a result, the flow velocity increases near the density interface, and the suspended sediment concentration increases near the bed.

In the perturbation problem, in response to a small sinusoidal disturbance imposed on the bed, the flow velocity and suspended sediment concentration, the thickness of the high concentration layer, the turbulent kinetic energy, and the dissipation rate are asymptotically expanded in the same sinusoidal manner. Substituting these expansions into the governing equations and dropping higher order terms of the small amplitude of perturbation, we derive linear homogeneous perturbation equations. A linear stability analysis is performed by numerically solving the perturbation equation and substituting the solution to the Exner equation representing the time variation of the bed elevation. The results are plotted as an instability diagram showing the neutral curves of the growth rate of perturbation on the wavenumber-densimetric Froude number plane. It is found that the minimum density Froude number (critical Froude number) for instability of the flat bed is approximately 0.5. In addition, the unstable region is narrowed in the direction of small wavenumbers near the critical density Froude number by the influence of density stratification.

Keywords: turbidity current, bed instability, boundary waves