The scales and profiles of submarine cyclic steps

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Froude-supercritical flow over an erodible bed is unstable and can form stable rhythmic bedform with long wave called cyclic steps. Cyclic steps are a series of upstream migrating steps which have the lee sides followed by stoss sides. It has been found that cyclic steps can be formed by turbidity currents which travel relatively long distance (long-runout turbidity currents). The flow is subcritical at the stoss side of the cyclic steps and it accelerates towards lee side end to become supercritical flow. The formation of cyclic steps formed by long-runout turbidity currents is presented in this study.

In this study, we assume an equilibrium state can be achieved in the high-concentrated lower layer near the bottom of long-run out turbidity currents. The high-concentrated layer can run out long distances and has little interaction with the upper layer. Then we integrate layer-averaged momentum and continuity equations along with the layer-averaged diffusion/dispersion equation of suspended sediment and the continuity equation of sediment (Exner equation) over the high concentrated lower layer. In the integration, the entrainment from the ambient sea water into the long-runout turbidity currents is negligible, since the Reynolds stress almost zero at the interface between the lower layer and the upper layer of long-runout turbidity currents.

The flow makes the transition from supercritical to subcritical regions through a hydraulic jump. The boundary conditions in this study are that the momentum is conserved before and after each hydraulic jump. Furthermore, the suspended sediment concentration is supposed to be continuous at the upstream and downstream sides of the hydraulic jump. The wavelength and wave height of cyclic steps are determined by the thickness of the high-concentration layer near the bottom. The thickness of this layer can be calculated by the fall velocity relative to the friction velocity, the slope of the ocean floor and the particle Reynolds number, and therefore it is reasonable to use the variables in the normal equilibrium state for the normalization.

We solve the two-point boundary value problem composed of the governing equations by the shooting method with the Newton-Raphson scheme. The calculation is started from the vicinity of the Richardson critical point to avoid singularities and it progresses towards upstream and downstream directions. Through calculation, we can generate the variations of suspended sediment concentration, layer-averaged velocity and wave height over one step wavelength. The profiles of cyclic steps depend on the Richardson number, the drag coefficient and the slope of the ocean floor. We could gain cyclic steps with various shapes depending on the parameters. The features of the obtained steps in the analysis bear an acceptable agreement with the field observations.

Keywords: Submarine bedform, cyclic steps, supercritical flow, long-runout turbidity currents