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津波溯上流による侵蝕と堆積の水理学的考察
Hydraulics of sediment erosion and reworking by surging currents

箕浦 幸治[1*]
MINOURA, Koji[1*]

[1] 東北大学理学研究科地学専攻
[1]Institute of Geology and Paleontology, Graduate School of Science, Tohoku University

Bottom irregularities and undulations affect the hydraulic behavior of currents, and a friction force working on bottom surface, as well as physical properties such as depth and velocity, is a significant factor responsible for flow conditions. Fluid pressure acting on the boundary between bottom currents and bed surface is a major cause of erosion and reworking of materials. Hydrological effects depending on ground-surface conditions were appreciated in the interpretation of sedimentary processes caused by the 1923 Kamchatka earthquake tsunami (Minoura et al., 1996). The tsunami deposit was very thin (~2 cm), however it was traceable for more than 6 km inland from the coast. Historical materials reveal that on 14 April rushing waves surged over the frozen snowfields of the Kamchatka plain. Through smoothing the snow surface by freezing, the critical tractive force finally exceeded the tractive force of flowing water, and thus rushing currents penetrated a depth of the plain, forming a landward tapering sand layer covering a wide range of the plain. In proportion to the increase in tractive force, the surface takes the force by shear stress. With increase in current speed, cohesive soft-sediment surfaces undergo shearing deformation depending on the scale of tractive force, and finally stress intensity escalates to a critical point of detachment threshold.

From late autumn to early spring, the rice fields in Tohoku are uncultivated, and paddy soils are exposed without vegetational cover. The 2011 Tohoku-Oki earthquake tsunami took place in early spring (11 March 20111), and it was five months after the final harvesting. The coastal zones of rice fields were subjected to torrential flooding. The sediment detachment threshold from the bed is defined as the force equilibrium between the tractive and resistant forces. The critical tractive force of cohesive soft surface is expressed as a function of yield stress (Ty1). Otsubo and Muraoka (1988) presented a mathematical model explaining the relation between tractive and resistant forces. When tractive shear stress reaches to yield stress, the threshold condition (Tc1) in mud transport is expressed in the following.

Tc1 = 0.27T0.6y1 (1)

The tractive force at the threshold of bed destruction (Tc2) is given as follows.

Tc2 = 0.79T0.94y1 (2)

The yield stress of paddy surface in the Sendai plain ranges from 1.27 to 2.35 N/m2 (Geospatial Information Authority of Japan, 1984). Thus, the tractive force of the threshold conditions of grain motion and initial surface erosion are calculated to be Tc1 = 0.31~0.44 N/m2 and Tc2 = 0.99~1.77 N/m2, respectively. The results indicate that the erosion of bed surface does not occur in case of the tractive force to be less than 0.31 N/m2. If the tractive force exceeds 1.77 N/m2, mass erosion of cohesive bed takes place. When the tractive force of currents exceeds the critical friction force of bottom surface, shearing stress starts to act on the surface. After passing the threshold of resistance, mud surface is deformed in response to increasing stress, and finally mass erosion of mud surfaces occurs.

Supercritical flows were generated where surging currents by the Tohoku-Oki tsunami crossed levees and roads to paddy surfaces, causing mass erosion of surfaces. In the paddy fields of Sendai mud chips and blocks were formed. The concentrated occurrence of cobble to pebble-sized balls of mud was frequently recognized on the downstream side of levees after the retreat of the 3.11 tsunami. Thin veneers of sand and mud covered the mud balls. Marks of migration on paddies indicated that rushing water moved them by rolling or slipping. Rice straw is chaffed by machine after harvesting, and small pieces of straw are scatted on rice fields. These pieces were included in mad balls, and it is interpreted that mud chips adhered paddy soils mixed with straw fragments during rolling on bottom surface and finally attained to forming cohesive mud balls.

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