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# Investigation of geotechnical properties and erosion characteristic of reservoir bed sediments

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## Background

In recent years, capacities of reservoirs in Taiwan have decreased due to the input of sediments from upstream watersheds, caused by the soil loss of slopeland under construction and during flood events. The lifetime of reservoirs is therefore reducing rapidly; thus dredging of reservoir bed sediments has become one of the major issues relating to soil conservation, water resources, and human society. Hydraulic desilting is one of the commonly applied measures for dredging of reservoir bed sediments in Taiwan. Accordingly, the hydraulic condition at which desilting of sediments initiates becomes a key factor for maintaining the features of targets and extending the lifetime of a reservoir.

## Objectives

This study focus on the fundamental geotechnical properties and erosion characteristic of bed sediments in Agongdian Reservoir, which locates in Kaohsiung City, Taiwan. First, we carried out geotechnical experiments to identify physical properties of the bed sediments. Then erosion experiments were carried out using a recirculating hydraulic flume under different flow conditions, created by adjusting different flow rates and slopes. Afterwards, we applied the modified Shields diagram to analyze the experimental data and determined the critical condition that the erosion of bed sediments initiates. With these results, we are expected to find out the appropriate hydraulic conditions for the bed sediments to be agitated and re-suspend, and provide operating strategies that promotes the efficiency of hydraulic desilting, in order to extend the lifetime of Agongdian Reservoir.

## Study Area

The study area is Agongdian Reservoir, which is located at Kaohsiung city (Fig.1), having the function of flood control, irrigation, water supply and tourism benefits as a mutil-target reservoir. The watershed area of the reservoir is equal to 31.87 km$^2$.

Two tributaries locating upstream, Wang-Lay creek and Zhuo-Shui creek contribute to Agongdian Reservoir; Agongdian creek locates downstream. The primary texture of surroundings in Agongdian watershed is composed of mudstone.

**Fig.1 The location of Agongdian Reservoir in Taiwan. (Source: Google earth, 2016)**

**Fig. 2 Agongdian Reservoir**

## Experiments and Results

### *Geotechnical Properties of Sediments*

In this study, bed sediments collected from Agongdian Reservoir are used as the soil specimens in the geotechnical tests and erosion flume experiments. The geotechnical tests and the corresponding results carried out are shown in Table 1 and Figures 3 and 4. Specifically, the sediments are classified as loam or silty loam with median size ($d_{50}$) of 0.032mm (geometric standard deviation $\sigma_g$ of 4.32), specific gravity of 2.56, PI = 3%, and organic matter content of 0.347%. In Figure 3, particle size distributions of sediments collected in Agongdian watershed from Yu (1997), Xie (1999), and this study are plotted together for comparision.

The manufactured standard quartz particles with similar geotechnical properties ($d_{50}$= 0.032mm, $\sigma_g$ = 4.10, and specific gravity = 2.65) of the reservoir bed sediments are applied in the erosion flume experiments as control groups in the preliminary tests.

**Table 1 Geotechnical properties of the Agongdian Reservoir bed sediments and the standard quartz sand.**

| Soil species | Median size ($d_{50}$) (mm) | Geometric standard deviation ($\sigma_g$) | Specific gravity (GS) | Plasticity index (PI) (%) | Organic matter content (%) |
|---|---|---|---|---|---|
| Agongdian Reservoir bed sediments | 0.032 | 4.32 | 2.56 | 3 | 0.347 |
| Standard quartz sand | 0.032 | 4.10 | 2.65 | None | None |

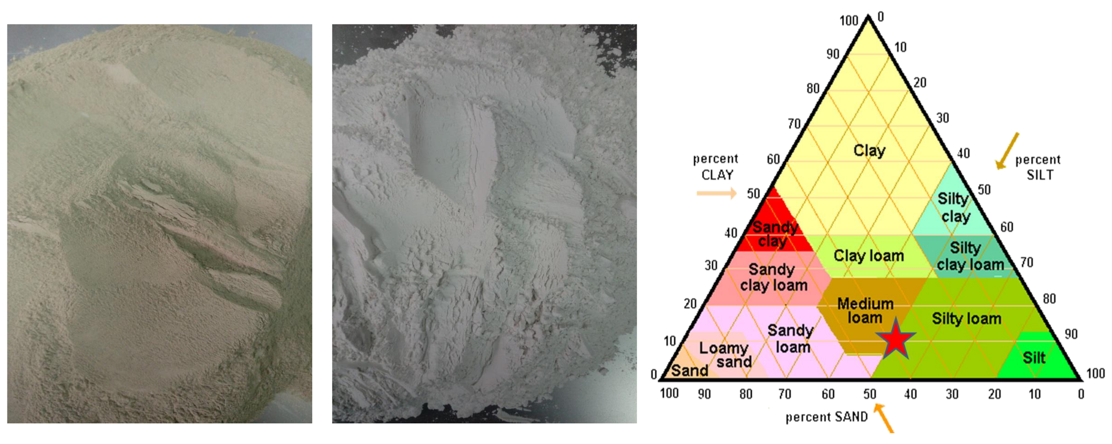


**Fig. 3 Bed Sediments of Agongdian Reservoir (left) and standard quartz particles (middle) and texture triangle diagram (right, the star pinpoints the texture of the bed sediments) (USDA-Soil Conservation Service, 1990).**

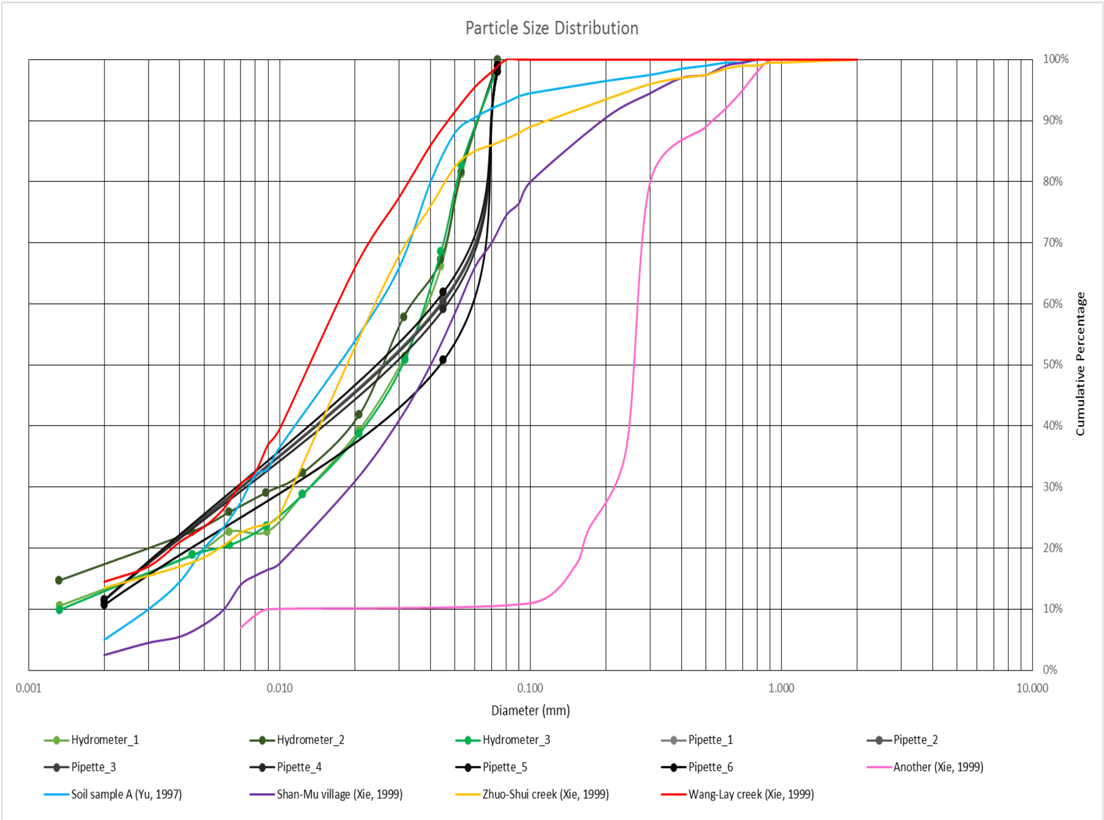


**Fig. 4 Particle size distributions bed sediments in Agongdian Watershed (data collected in Yu, 1997; Xie, 1999; this study).**

### *Erosion Flume Experiments*

The erosion experiments are carried out in a circulating and tilting flume as shown in Figure 5, which is 3 m long, 1.2 m wide and 0.15 m deep. The setting slopes of testing tries are 2x10$^{-3}$ and 8x10$^{-3}$ (which is confirmed by the average slopes and maximum slopes of Agongdian Reservoir and its tributaries). The setting discharge of tests are 25 cm$^3$/s and 50 cm$^3$/s. Before the sediments are poured into the flume, the sediments are mixed with tap water with the ratio of 1 to 1.5 as slurry, in order to guarantee the saturated condition as that in the reservoir. The slurry then is poured in to the flume until the sediment height reaches 5 cm from the channel bottom. Afterwards, the slurry are put for 24 hours settling as natural consolidation. The 24-hour resting time is confirmed by measuring the turbidity of the water just above the sedimentation surface along the resting period (Fig.7).

**Fig. 5 The hydraulic flume for erosion experiments.**

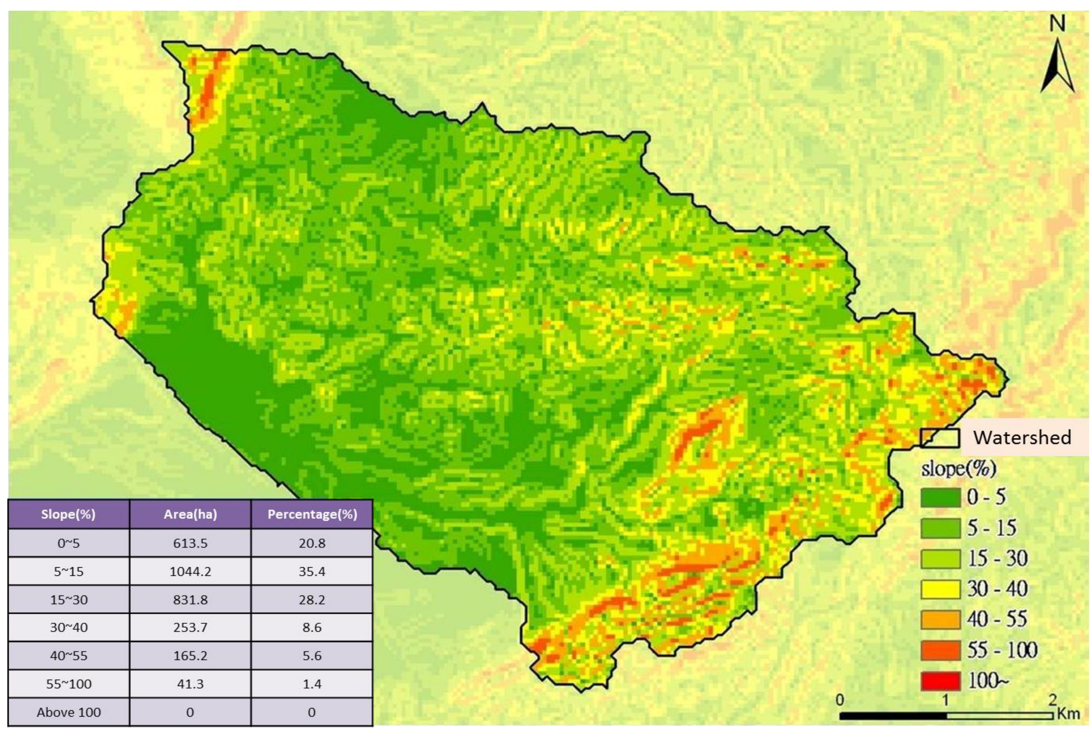


**Fig. 6 Slope diagram of Agongdian Watershed (Source: Water resources bureau in southern district of water resources agency, 2014).**

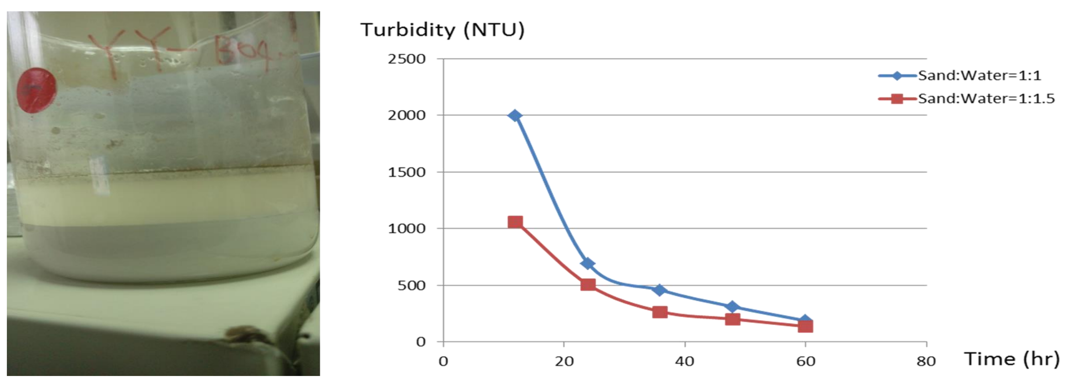


**Fig. 7 The settling experiment of standard quartz particles. There is a sand-water interface showing in the left picture and the turbidity measured along the resting period are shown in the right.**

### *Data Analysis*

At each flow condition, the magnitude of bed shear stress at can be determined by measuring the near-bed flow velocity and water depth, and substituting into the following equations (Wu, 2002) derived from Manning's equation (Gauckler, 1867; Manning, 1891) and Darcy-Weisbach equation (Darcy and Weisbach, 1991):

$$\tau_x = \frac{\rho g u}{\left(\frac{1.486h^{1/6}}{n}\right)^2}(u^2+v^2)^{1/2} - \xi {v_a}^2 cos\psi - 2\rho h\omega v sin\varphi$$

$$\tau_y = \frac{\rho g v}{\left(\frac{1.486h^{1/6}}{n}\right)^2}(u^2+v^2)^{1/2} - \xi {v_a}^2 cos\psi + 2\rho h\omega u sin\varphi$$

Where n is the Manning roughness coefficient; ξ is experience wind shear coefficient; $v_a$ is wind speed and wind direction (ψ); ω is the angular rate of rotation of the Earth; φ is the local latitude; 1.486 is the unit conversion of metric system to imperial system.

In the abovementioned formula, the two items at the rear formula are correction function of wind speed and wind direction. Assuming there is no wind during experiment, so that the two items can be ignored.

The erosion rate of sediments during the testing trials are determined by the curve of turbidity versus bed-load concentration as shown in Figure 8.

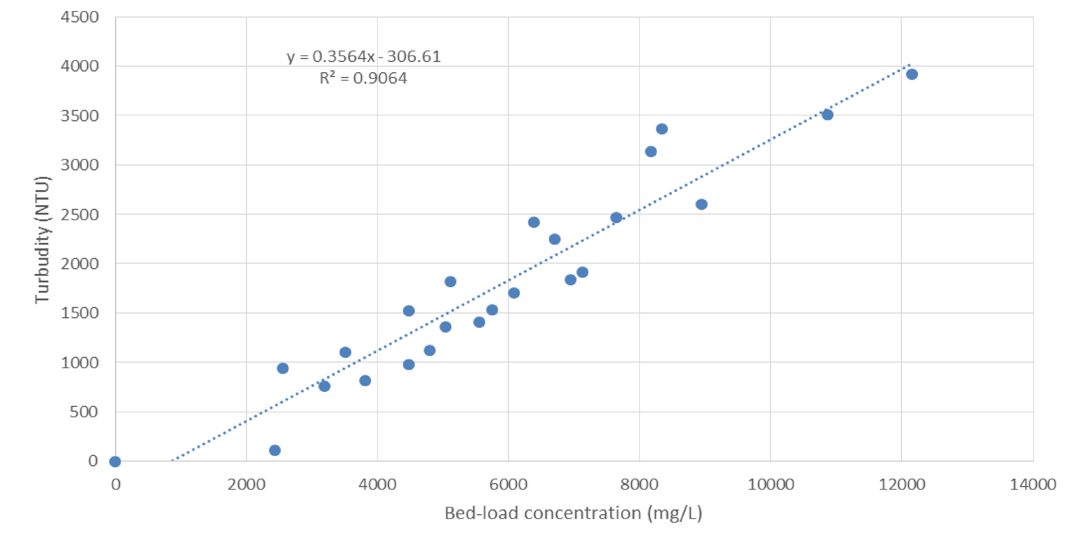


**Fig. 8 Turbidity versus bed-load concentration.**

Afterwards, curves showing the erosion rates under different hydrodynamic conditions (represented by different values of bed shear stress) are plotted to determine the erosion threshold of the reservoir bed sediments. Consequently, quantitative relationships are expected to be proposed among the erosion threshold (e.g. critical shear stress) and various sediment geotechnical properties.

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