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Enhanced hydrosuction performance for cohesive sediment removal in low-head reservoirs

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Abstract Deposited sediment removal or dredging is generally required in many hydro-system projects. Siphon dredging or hydrosuction bears many advantages including low energy consumption, minor turbidity generation and ability of localized dredging. A new device attached to a regular siphon inlet is introduced which produces a swinging action by means of a simple mechanism. Equipped siphon sweeps a larger area than what a regular siphon does and enhances the hydrosuction performance for cohesive sediment removal. Regular and equipped siphon performances for dredging non-cohesive and cohesive sediments were investigated experimentally. Time to reach equilibrium scour was determined and applied for all the tests. The equipped siphon generated larger scour holes in cohesive sediment type than that of the regular one and enhanced sediment removal process. This could be attributed to the swinging action of the siphon inlet which strikes the scour hole wall and acts against the cohesion property of the sediment.

1. Introduction

Reservoir sedimentation has been recognized as the main factor drastically influencing dam's life span. The phenomenon becomes more important in arid and semi-arid regions, where the occurrences of flash floods are more frequent during which large amounts of sediment are transported. According to the International Commission On Large Dams, ICOLD, around 0.3 percent of large dam reservoirs capacity decreases annually due to reservoir sedimentation [1]. Some methods were implemented by engineers to act against reservoir sedimentation, including turbidity current ventilation, free flushing and pressurized flushing, mechanical excavation of dry materials, and siphon dredging [2].

Solid deposit could be removed by means of a siphon action, which is termed hydrosuction when it applies to reservoirs sediment removal. In this method, the flow field velocity in the vicinity of the siphon inlet generates sufficient shear stress to establish reservoir bed scour. The mixture of the water-scoured materials is then removed through the siphon to the downstream side of the reservoir.

Compared to other dredging methods, hydrosuction might remove a smaller volume of sediment in a specific period of

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time, but it exhibits some advantages such as local dredging capability, low turbidity generation, ease of use, flexibility in sediment release management and cost-effectiveness. Fine sediment attracts most organic and inorganic contaminants and bears high tendency for suspension during dredging process. Suspended sediment is difficult to collect and could easily travel to downstream reaches, which ultimately spread the pollution along the water course. Low turbidity generation during a dredging process and the capability of local sediment removal are the main advantages of hydrosuction, which make its application in such circumstances appropriate [3,4].

The first hydrosuction application was reported form Algeria where a 0.61 m diameter pipe of 1600 m length was used to dredge 1.4E6 m^3 of silt and clay during a 2-year period with an average mass concentration of 3% [5]. Also, about a century ago siphon dredging had been applied to remove deposited sediments from the intake mouth of the 21-m-high Rioumajou dam, in France. The siphon carried 15 kg of sediment in 1 cm s water [6]. It seems that China is the most experienced country in hydrosuction dredging. In this country, the sediment laden flow of the hydrosuction dredging systems has been supplied to agricultural croplands to fertilize the soil. The hydrosuction systems in China were employed in dams having heights between 15 and 35 m. Also, the successful application of hydrosuction in 1.8 m height Atkinson weir on Elkhorn River, which lacks desilting structure, was reported. The employed hydrosuction system removed as much as the annual sediment inflow [5].

Slotta [7] applied the dimensional analysis and proposed some relationships to represent the scour hole geometry for different types of experimentally tested materials. Gladigau [8] studied the influence of the suction inlet shape on the material removal. He reported insignificant impact of straight and bell-mouth type tube inlets on the geometry of scour hole. Salzmann [9] examined the hydraulic behavior of the flow around suction inlets in the vicinity of sand beds. He presented the velocity and pressure distribution around suction inlets in graphical forms and claimed that the potential flow theory could be applied for studying the flow condition around the suction inlet.

Rehbinder [10] followed the potential flow theory and considered the suction inlet as a sink point. He resolved the acting forces on sediment grains in two components, i.e. forces generated by seepage flow phenomenon and shear forces produced in the boundary layer in the immediate vicinity of the bed. Rehbider [10] indicated viscous flow present in a cylindrical region surrounding the pipe inlet where $0 < r < Z_o \frac{\sqrt{2}}{4}$, in which Z_o is the distance between the suction inlet mouth and the undisturbed bed surface. He also observed that the location of initiation of motion takes place at $0.8 < \frac{r}{z_o} < 1.4$ and the maximum force acts at $r \approx 0.8 z_o$. Rehbinder revealed that the lift force acting on grains is a function of the vertical pressure distribution in the sediment layer and reported that the ratio of lift force to shear force changes between 2 to 20.

Ullah [4] provided relationships to describe the scour hole geometry at the equilibrium condition. He concluded that the scour hole profiles are similar in shape and could be represented by a common relationship. He also found that absence of a vortex beneath the suction inlet leads to formation of a conical heap at the center of the scour hole, while the presence of the vortex generates asymmetric scour hole shape and random values of sediment removal.

Recently, Chen et al. [11] proposed an inclined cutting shape for the siphon inlet along with peripheral holes slightly above the inlet to overcome chocking problems. They also connected the siphon inlet to a floating tank in order to generate vertical movements and reported the best performance of the system in connection with the inlet diameter to enhance chocking prevention.

The main objective of this research was to enhance the performance of the hydrosuction dredging by installing a specific turbine like device which locally disturbs the bed. This feature empowers the hydrosuction action and provides it with the ability of dredging cohesive sediment. The influence of installing the device on sediment removal efficiency for dredging cohesive and non-cohesive sediment is examined and reported.

2. Experimental setup and procedures

In this research a new device is developed which functions based on turbine principle and improves siphon dredging performance for cohesive sediment. The device should be installed at the siphon inlet to generate swinging or wobble motion with the aid of a special mechanism introduced herein. The mentioned action of suction inlet leads to sweeping a wider area compared to that of stationary siphon and prevents choking of the siphon.

As indicated in Figs. 1 and 2 the device consists of a cylindrical casing with an inlet and an exit. The exit is connected to the siphon mouth. Inside the cylindrical chamber an impeller is installed that rotates by the flowing water similar to the rotation of a turbine runner. The impeller shaft extends outside the casing on which a disk is connected. The disk rotates at the same speed of the impeller. The wobble motion of the device is generated by means of the rotation of an asymmetric weight installed on the disk. The disk and the connected weight are covered by a cap which was removed for presentation purpose in Fig. 1. Fig. 2 presents the details of the device parts.

During the first stage of the design, different impeller configurations, as indicated in Fig. 3, were manufactured and tested. The preliminary test indicated that impeller of type C performed better than the other two types did.

To examine the device performance a series of experiments were carried out on a regular siphon and a siphon equipped

Figure 1 The proposed device.