Journal of Hydrology 564 (2018) 773–784

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

On resuspension and control of reservoir sediments by surface waves and point absorbers

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A R T I C L E I N F O

This manuscript was handled by Corrado Corradini, Editor-in-Chief, with the assistance of Subashisa Dutta, Associate Editor

Keywords:
Riverbed
Resuspension
Dams
Loss of river deltas

A B S T R A C T

Consideration is given to a novel approach for resuspension and control of sediment in reservoirs which nowadays and after more than six decades of research remains as the most serious technical problem faced by dam industry. Here, it is proposed the generation of mild surface waves in the reservoir which – because the physical nature of the waves, will spread throughout the reservoir. Then, by using a farm of point absorbers – or technology akin as used in ocean energy conversion, the energy transported by the waves can be transformed into a continuous injection of water flow in the riverbeds balancing the gravitational settling and then in the resuspension and control of sediment settlement. Utilizing a simplified physical model an estimation of the area of riverbed covered in comparison with the area of point absorber needed was derived as function of several parameters. Methods for wave generation were briefly discussed and Computational Fluid Dynamics (CFDs) simulations performed being in good agreement with the theoretical estimations. The proposed concept is presented as a promising alternative technique which can contribute to mitigate the serious global problem of land loss in the river deltas as well as increasing the storable capability and life of large dams.

1. Introduction

When a river is stilled behind a dam, the sediments it contains sink to the bottom of the reservoir. The amount of a rivers total sediment load captured by a dam – generally known as its "trap efficiency" – approaches 100 per cent for many projects, especially those with large reservoirs. As the sediments accumulate in the reservoir, there are two serious problems, namely: On one hand, the dam gradually loses its ability to store water and then imposing a serious threat to the sustainability of hydropower by affecting the safety of the dam, reducing its energy production, storage, discharge capacity and flood attenuation capabilities and thus being the life of a reservoir usually limited by sediment accumulation, and on the other hand dams completely change the relationship of water and land with the obstruction of the transport of sediments downward putting in danger the survival of the river deltas. After more than six decades of extensive research in several aspects (Gill, 1979; Caputo and Carcione, 2013; Parsaie et al., in press; Alighalehbabakhani et al., 2017; Guan et al., 2018; Park and Hunt, 2017; Yin et al., 2014), including modern forecasting techniques, Taormina et al. (2015), Olyaie et al. (2015), Chen and Chau (2016), Wang et al. (2013), Wu and Chau (2006) and Chau (2017), there is limited guidance on how best to address the problem. Today management options available for dealing with sediment problems could be classified into 3 groups of measures for countering reservoir sedimentation as is illustrated in Table 1, Liu et al. (2017) and Spreafico and Lehmann (2009). Nevertheless all these measures, can be observed much more as strategies for managing reservoir sedimentation, Wang and Hu (2009) rather than technological approaches, and as such, they are of limited application with age specific dependency the specific geometry of the reservoir, climate, as well as its capacity, Kondolf et al. (2014). Nowadays, sedimentation is still probably the most serious technical threat faced by the dam industry, for example, a recent estimate indicates that the global reservoir storage capacity would be half-loss by 2100, Annandale (2013). For those readers interested in the history and politics aspects of the dam problem, the book by McCully (2001) is recommended, and an up to date review in sediment management can be found in Kondolf et al. (2014).

However, without doubt, the larger concern on trapping of sediment by large dams is on the drastic environmental impact caused which have become so controversial. For the sake of illustration of the severity of the problem, let us consider two cases for two different continents. The Ebro Delta – in Catalonia, Spain, is a wetland of international importance, and is considered one of the coastal systems most vulnerable to climate change in the European Union. The Delta is currently undergoing a loss of wetlands and rice paddies because of coastal regression, caused by diminishing fluvial sediments which are retained in

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https://doi.org/10.1016/j.jhydrol.2018.07.054
Received 24 December 2017; Received in revised form 15 June 2018; Accepted 20 July 2018
Available online 27 July 2018

Nomenclature

A_d	area of the river bed
A_p	area of the point absorber
A_s	area of the river bed lifted by the point absorber
b	crest width
C_D	drag coefficient
d_p	diameter of particle sediment
g	gravity
h	water reservoir depth
$\overline{H}$	average vertical displacement of the PA
L_r	width of reservoir
n_s	number of particles per volume
P	power of the wave
P_g	power of the wave generator
Q_c	cavity water flow rate
Q_d	hydroelectric water flow rate
Re_p	particle Reynolds number
t	time
T	wave period
u_{mf}	minimum fluidizing velocity of the bed
u_u	upward velocity
u_d	downward velocity
u_t	terminal velocity

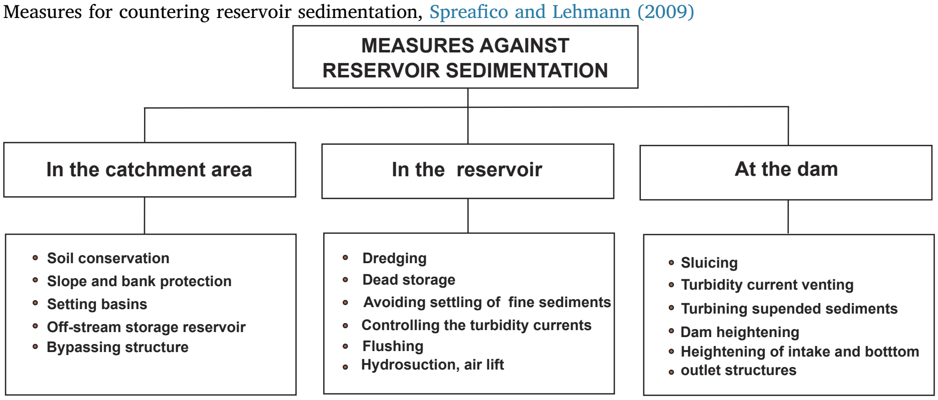
Greek symbols

λ	wavelength
δ	thickness of the sediment bed
η	efficiency in mechanical conversion
ρ	density of water
ρ_s	density of particle
ε	void fraction
ϕ_s	sphericity of particle
ω	wave frequency
Γ	area of riverbed covered divide with the area of the point absorber defined by Eq. (10)

Subscripts symbols

s	sediment
p	pressure absorber, particle
u	upward
d	downward

Table 1
Measures for countering reservoir sedimentation, Spreafico and Lehmann (2009)



the reservoirs of the basin. The coast is retreating by more than 10 m per year in the mouth of the delta, where 150 ha of wetland were lost between 1957 and 2000. The problem is accentuated by the decline in the elevation of the delta. About half of the delta (15,000 ha) could be affected by this phenomenon during 21 st century.

In China, in the Mekong River basin, largely undeveloped before 1990, 140 dams are built, under construction, or planned, Grumbine and Xu (2011) and Kondolf et al. (2014), and a systematic analysis of sediment trapping by the planned dams indicates that full completion of these 140 dams would result in a 96% reduction in sediment load to the Mekong Delta, i.e., the Delta would receive only 4% of its natural sediment load.

The search for innovative engineering methods has led the department of fluid mechanics at the University Polytechnic of Catalonia (UPC) within the framework of the European project LIFE-EBRO-ADMICLIM (*Adaptation and Mitigation Measures to Climate Change in the Ebro Delta*), EBRO-ADMICLIM project to develop a novel solution for the resuspension and control of reservoir sediments in dams.

The core idea is the generation of mild surface waves in the reservoir which – because the physical nature of the waves, will spread throughout the reservoir and then, by using a farm of point absorbers – or technology akin as used today in ocean energy conversion, the energy transported by the waves can be transformed into a continuous injection of water flow in the riverbeds balancing the gravitational settling and then in the resuspension and control of sediments.

2. Methods

Having defined our conceptual framework, we will proceed with a first theoretical treatment of the proposed technique.

To begin with, let us consider Fig. 1 where it is shown the schematics of the core idea here discussed. In this figure, a conventional reservoir where sediments are accumulated in the riverbed, mild waves are deliberately created on the surface of the reservoir by a proper wave-generator. At this point, let us do not worry about the wave-generator, we will address this issue in the last part of the manuscript. For the moment, let us say that waves are continuously generated and spreading throughout the surface of the reservoir.

Now, as is depicted in the same figure, a farm of Point Absorbers (PAs) is placed. In brief, a PA is just a device which can be a floating structure that heave up and down on the surface of the water or submerged below the surface relying on pressure differential as is sketched in Fig. 2 where some part of the PA structure acts like a piston to pressure changes caused by the passage of the wave.

2.1. Theoretical calculations

Bearing in mind the above idea, we will proceed with some