Ecological Engineering 71 (2014) 21–31

Contents lists available at ScienceDirect

Ecological Engineering

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

Simulation of sediment retention effects of the double seabuckthorn plant flexible dams in the Pisha Sandstone area of China

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ARTICLE INFO

Article history:
Received 10 February 2014
Received in revised form 12 May 2014
Accepted 11 July 2014
Available online 31 July 2014

Keywords:
The double seabuckthorn flexible dams ("SFDs")
Sediment retention effects
Pisha Sandstone
Planting parameters
Ecological restoration
One-dimensional sediment and water model

ABSTRACT

The Pisha Sandstone area is located in the triangle region close to Shanxi Province, Shaanxi Province, and Inner Mongolia Autonomous Region in Northwestern China. This area is the main source of coarse sediment entering into upper and middle reaches of Yellow River of China. The area is often called as "the most severe soil and water loss area in the world" and compared to "the cancer of the earth" due to the extremely serious soil and water loss and poor eco-environment. To control the coarse sediment delivering into Yellow River and restore the ecology of this area, the seabuckthorn plant flexible dam, a new ecological engineering, was proposed and used widely in this area. In this paper, the sediment retention effects of the double seabuckthorn flexible dams ("SFDs") after seven years in the Pisha Sandstone gully were simulated using one-dimensional sediment and water mathematical model. Based on the computational results, several major design and planting parameters and their values were analyzed and discussed, including the dam length, the dam gap, the roughness as well as the slope of gully bed. The interaction among these parameters was also discussed according to the simulation results. We found that the sediment retention effects of the double seabuckthorn plant flexible dams were also dependent on the rainfall events and the gully topography. This study provides the theoretical proof for the design and planting of the double seabuckthorn flexible dams (i.e., a new ecological engineering) in the Pisha Sandstone area.

1. Introduction

A series of problems such as soil erosion, land degradation, shortage of water resources, forestry degradation, ecology deterioration, etc., were produced due to human activity, which is mainly associated with soil and water loss. Soil and water loss is becoming a common severe problem in arid or semi-arid area in the world. It is well known that plant or biological measures or other ecological engineering relevant to vegetation were the most essential methods to control soil erosion and can attain good eco-environment (Liffen et al., 2011; García-Lledó et al., 2011; Hussein et al., 2007; Cao et al., 2006; Li et al., 2010; Stephanie et al., 2005; Slattery and Phillips, 2011). Moreover, researches on utilizing various kinds of plant to control soil and water loss have been conducted for a long time (Sandercock et al., 2007; Cao et al., 2007a,b; Mariet et al., 2005; Zhao, 2001; Cheng et al., 2004; Halmar et al., 2003). Each kind of vegetation has its attributes and different areas have various physical features including soil composition, soil property, topography, slope and orientations, etc. Thus, proper selection of vegetation is a very important to control soil erosion of specific area. And some planting approaches or ecological engineering techniques are also very vital for erosion control and nutrient loss prevention (Susanne and Christophe, 2012; Xu, 2005; Sandercock and Hooke, 2011). Currently, great attention has been paid to the various ecological engineerings in order to control soil erosion and to restore the ecology of arid area (Otero et al., 2011; Alexia et al., 2012; Wang et al., 2007; Rasmussen et al., 2011a). The ecological engineering has great potential for the improvement and restoration of eco-environment (Wu and Feng, 2006; Black and Aase, 1988; Grewal et al., 1994; Machito, 1996; Gottschall et al., 2007; Kim and Emile, 2004; Zhun et al., 2012).

The concept of connectivity has long been used in landscape ecology relevant to biotic links (Bracken and Croke, 2007; Western et al., 2001). The connectivity is taken here to mean the physical

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http://dx.doi.org/10.1016/j.ecoleng.2014.07.050
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Nomenclatures

A	flow cross section area (m^2)
Q	mean section discharge ($m^3\,s^{-1}$)
q_L	lateral discharge of unit flow distance ($m^3\,s^{-1}\,m^{-1}$)
V	mean section velocity (m^3)
ξ	local water heat loss efficient
z	water elevation (m)
K	discharge modulus ($\equiv ACR^{1/2}$)
C	Chezy coefficient ($\equiv(R^{1/6})/n$) ($m^{1/2}\,s^{-1}$)
R	hydraulic radius (m)
n	Manning's roughness coefficient-dimensionless coefficient
g	Acceleration due to gravity ($m\,s^{-2}$)
S	mean sediment concentration in cross-section ($kg\,m^{-3}$)
Q_S	mean transport sediment rate in cross-section ($kg\,s^{-1}$)
$\gamma_s{'}$	gravity per unit dry sediment ($N\,m^{-3}$)
A_S	bed sediment erosion or deposition area in cross-section (m^2)
q_s	lateral sediment transport mass per unit flow distance per unit time ($kg\,m^{-3}\,s^{-1}$)
x	first horizontal Cartesian coordinate (hereby aligned with the predominate flow direction) (m)
t	flow time (s)
g_b	sediment transport rate per unit channel width ($t\,s^{-1}$)
d_m	medium grain size of bed sediment (m)
n'	Manning's roughness coefficient corresponding to grain resistance energy slope ($\equiv(d_{90})^{1/6}/26$ or calculated by Moddy diagram)
d_{90}	the sediment grain size corresponding to 90% sediment mass in grain size distribution curve (m)
γ	gravity per unit water volume ($kN\,m^{-3}$)
γ_s	gravity per unit wet sediment volume ($kN\,m^{-3}$)
ρ	density of water ($kg\,m^{-3}$)
ρ_s	density of sediment ($kg\,m^{-3}$)

linkage of sediment transport, which can allow sediment, microorganism and fauna to deliver from one location to another and has the potential for those to pass through the system (Hooke, 2003). Vegetation was the best selection for creation of the connectivity. Use of vegetation is being increasingly advocated as a more sustainable approach to erosion control, land degradation and desertification (e.g. Millenium Ecosystem Assessment, 2005). Vegetation reduces sediment delivery by both decreasing erosion and increasing deposition. It performs this through two major effects: (i) by increased roughness and resistance effects on the hydraulics of flow, decreasing velocity and bed shear stress (Koskiaho, 2003; Fathi-Maghadam and Kouwen, 1997; Ree, 1958); (ii) by increasing strength of the substrate, mainly through the effects of roots and branches (Wilson, 2007). Detailed research on interactions of flow and plants mostly comes from the results of flume experiments, most of them using simulated vegetation but not real vegetation (Lopez and Garcia, 1998). Vegetation measures have been widely used in soil erosion control and the integrated watershed management including improving water quality, stabilizing river bank, and lessening sand storm. Vegetation barriers along the contour line have proven to be an effective ecological measure used to control soil erosion and restore ecology in arid or semi-arid areas (Reeder et al., 2005; Oteroa et al., 2011; Rasmussen et al., 2011b). Rao et al. (1991) managed *Leucaena leucocephala* as hedgerows on Alfisols and Vertic Inceptisols in semi-arid area in India. It was found that hedgerow intercropping was helpful for soil richness and water conservation. Spaan et al. (2005) again studied vegetation barrier composed of the *Andropogon gayanus* (a species of dense grass), he found this grass had notable effectiveness in reducing soil loss in the Africa sub-Saharan semi-arid area. Presently, the vegetation filter strip (VFS) or the vegetation buffer strip (VBS) or riparian buffer strip (RBS) were also good ecological measures used to detent sediment and restore ecology in riparian system. These filter or buffer strip, besides the effects of protecting soil and intercepting sediment, can yet safeguard water body not to be polluted by non point source pollutants (Lee et al., 2003; Ghebremichael et al., 2008; Udawatta et al., 2010). In Europe, over the past 40 years, the ecological engineering of forests to protect against mass movement including shallow landslides, debris flows, avalanches and rock falls has increased, particularly with regard to avalanches and rock fall. Generally speaking, using plant or vegetation controlling soil and water loss and recovering regional ecology have made a great progress and good effects in many regions.

The seabuckthorn, a kind of native vegetation of Loess plateau in China. Hippophae well known as seabuckthorn, is a kind of multipurpose plant including soil erosion control, biological nitrogen fixation and medicinal use (Yogendra Kumar et al., 2011; Purushothaman et al., 2008). There are two main species of seabuckthorn, i.e., *Hippophae salicifolia* D. Don and *Hippophae rhamnoides* L., in China. *H. salicifolia* belongs to a shrub-to-tree growing mainly in the Himalayan region, however *H. rhamnoides* is bushy growing predominantly at higher altitude in China, and it is widely distributed in Asia and Europe. Natural property of the seabuckthorn includes strong drought endurance, tolerance to sterile soil and powerful self-generated ability, thus being a pioneering plant to control soil and water loss within the extremely poor physical area with high sediment yield.

The Pisha Sandstone area is located in the joint region close to Shanxi Province (Chinese conventionally called as "Jin" for short), Shaanxi Province (Chinese conventionally called as "Shan" for short), and Inner Mongolia Autonomous Region (Chinese conventionally called as "Meng" for short) in northwestern China. The Pisha Sandstone covers most of the Erdos Plateau and Inner Mongolia Autonomous Region of northwestern China and becomes a part of watershed of upper and middle reaches of Yellow River in China. The Pisha Sandstone is composed of loosely bonded sandstone mainly formed via coarse sediment (>0.05 mm in diameter) and thus has better permeability. More previous investigations have proven that it is the major source of coarse sediment (>0.05 mm) into the upper and middle reaches of Yellow River of China. The Pisha Sandstone is hard when it is dry but soft and loose when wet (Bi et al., 2003; Li and Bi, 2005). And it has so very little nutrition that most of the species of vegetation can hardly live in this area. Just because of this property, local inhabitant compared it to arsenic and conventionally named it as the Pisha Sandstone. The soil and water loss of this area is very serious during rainfall events. The soil erosion module is actually 40,000 $t\,km^{-2}$ and thus it is called as "the most severe soil erosion in the world", whilst the eco-environment of this area is getting poorer and poorer and thereby this area is compared to "the environmental cancer in the earth". Therefore, soil erosion control and the restoration of ecology of this area are very important.

Conventional approaches to erosion control were to build check dams or to use blanket modification of upslope or upland, however, these are not radical measures. For instance, the check dam can easily produce many problems such as dam seepage, dam breakup by flood and thereby it would become no use after deposited by enough sediment. More badly, it cannot create a passage for flora and fauna to freely migrate between upper and lower gully.