Geomorphology 248 (2015) 172–184

Contents lists available at ScienceDirect

Geomorphology

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

Flow, turbulence, and drag associated with engineered log jams in a fixed-bed experimental channel

Sean J. Bennett [a,*], S. Mohammad Ghaneeizad [b], Michael S. Gallisdorfer [a], Donghua Cai [a], Joseph F. Atkinson [b], Andrew Simon [c], Eddy J. Langendoen [d]

[a] Department of Geography, University at Buffalo, Buffalo, NY 14261-0055, USA
[b] Department of Civil, Structural, and Environmental Engineering, University at Buffalo, Buffalo, NY 14260, USA
[c] CardnoENTRIX, 1223 Jackson Avenue East, Suite 301, Oxford, MS 38655, USA
[d] USDA-ARS National Sedimentation Laboratory, Oxford, MS 38655, USA

ARTICLE INFO

Article history:
Received 27 March 2015
Received in revised form 28 July 2015
Accepted 30 July 2015
Available online 4 August 2015

Keywords:
Engineered log jams
Drag force
Physical model
River restoration

ABSTRACT

Engineered log jams (ELJs) have become attractive alternatives for river restoration and bank stabilization programs. Yet the effects of ELJs on turbulent flow and the fluid forces acting on the ELJs are not well known, and such information could inform design criteria. In this study, a fixed-bed physical model was constructed to assess the introduction of ELJs along the Big Sioux River, SD. Two ELJ types were examined, referred to as ELJ-1 and ELJ-2. Both types were deflector jams, where ELJ-1 was rectangular and ELJ-2 was triangular, and oriented with one side attached to the channel bank. They were deployed either as single structures or in groups of two or three on the same side of the channel and at different separation distances. Results show that (1) time–mean and turbulent velocities and bed shear stresses were measurably altered near the ELJ, but spatially averaged flow just upstream and downstream of the structure was unaffected; (2) streamwise drag forces measured for the ELJs were significantly larger than the transverse forces, and the derived drag coefficients for the single structures were 2.72 ± 0.19 for ELJ-1 and 1.60 ± 0.37 for ELJ-2; and (3) the presence of an upstream structure created a near-bank wake region that extended a distance of more than 30 flow depths downstream, which greatly reduced drag forces and drag coefficients observed for the downstream structure by as much as 80%. These observations are further evidence of the efficacy of ELJs in providing near-structure scour pool development and bank protection downstream, and they can be used to inform and assess the design of ELJs for use in river restoration and bank stabilization projects.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Natural accumulations of large wood (LW) are integral and beneficial components of many river systems worldwide. Geomorphically, LW can affect time–mean and turbulent velocities (Daniels and Rhoads, 2003); it can create patterns of localized erosion and deposition (Abbe and Montgomery, 1996; Buffington et al., 2002; Wallerstein and Thorne, 2004); and its placement has been linked to the development, spacing, and stability of pools (Montgomery et al., 1995). Ecologically, LW provides essential habitat and ecosystem services (Bisson et al., 1987; Lester and Boulton, 2008), it enhances hyporheic flow exchange (Lautz et al., 2006), and it can sequester nutrients and facilitate their processing in situ (Lester and Boulton, 2008; Flores et al., 2011). At relatively larger time and space scales, LW can positively influence the dynamic stability and integrity of fluvial landscapes (Collins et al., 2012).

For these reasons, engineered log jams (ELJs) have become attractive alternatives to conventional in-stream structures used for river restoration and channel stability. For example, ELJs can be employed in river restoration projects for grade control and flow redirection (Abbe and Brooks, 2011). Abbe et al. (2003a) and Abbe et al. (2003b) showed that ELJs installed along the North Fork Stillaguamish River, WA, improved habitat indices, decreased bank erosion, and trapped additional wood in transit. Shields et al. (2004) described the design and installation of ELJs along Little Topashaw Creek, MS. While several structures failed because of a subsequent high-flow event and inadequate anchoring, the ELJs produced positive responses in fish communities (Shields et al., 2006). Brooks et al. (2004) reported on the installation of ELJs along the Williams River, NSW, AUS, which resulted in increased pool and riffle area and pool depth, increased sedimentation and channel complexity, and improved fish indices. Despite these successes, current design criteria for ELJs are sparse (see Shields et al., 2004; Brooks et al., 2006), and the morphodynamic responses of river corridors to the introduction of ELJs could be better predicted. The primary reasons for these perceived deficiencies may be attributed to (i) the relatively new technology and concept of ELJs, (ii) the lack of widespread deployment of ELJs by practitioners, and (iii) limited data on ELJ post-project assessment.

* Corresponding author.
E-mail address: seanb@buffalo.edu (S.J. Bennett).

http://dx.doi.org/10.1016/j.geomorph.2015.07.046
0169-555X/© 2015 Elsevier B.V. All rights reserved.

Scaled models of river prototypes in laboratory channels can help fill these important gaps in the understanding of river morphodynamic responses to ELJs and to further develop and refine design criteria. Gallisdorfer et al. (2014) reviewed the basis for scaled physical models of ELJs and presented the necessary relations for analyzing the introduction of ELJs into the Big Sioux River, SD, USA, as an example application. The Big Sioux River is a relatively low sinuosity river with a very fine sand bed flowing across glacial outwash and alluvial sediments where the primary land use in the watershed is agriculture (row crops and pasture). The proposed installations of ELJs along this river are to reduce bank erosion and to decrease suspended sediment fluxes to downstream environments, which have adversely affected fish and aquatic life within the river (SDDENR, 2014). Using the 1.5-year recurrence interval flow rate, spatially averaged dimensions of the river channel, and characteristics for the available wood, Gallisdorfer et al. (2014) provided the scaling relations required to construct fixed- and movable-bed physical models and the design of two different ELJ structures. The focus of the current paper is to present experimental findings for the fixed-bed model where two types of ELJs were deployed alone and in groups of two or three of the same structure. The objectives are (i) to document the effects of ELJs on the time–mean and turbulent flow and boundary shear stress as compared to a channel without any structures present and (ii) to define the fluid forces acting on the structures, through direct and indirect means, using a variety of structure configurations. These experimental results should inform design criteria for ELJs in river restoration and bank stabilization programs.

2. Methodology

Following Gallisdorfer et al. (2014), dimensional analysis indicates that the primary scaling relationship for the model is the Froude number Fr, where the ratio (subscript r) between the field prototype (subscript p) and physical model (subscript m) is set to unity,

$$Fr_r = \frac{Fr_p}{Fr_m} = \frac{u_r}{\sqrt{g_r h_r}} = 1 \tag{1}$$

where u is time-averaged downstream flow velocity, g is gravitational acceleration, and h is average flow depth. To build the fixed-bed model, channel cross section data provided by the City of Sioux Falls were averaged to determine representative reach dimensions, and a flow frequency analysis of data collected near Dell Rapids, SD (USGS 0648100) defined the design discharge Q with a recurrence interval of 1.5 years ($Q_{1.5}$). Additional considerations for model construction included the following: (i) flow was fully turbulent, (ii) surface tension was ignored, (iii) the vertical scale was distorted relative to the horizontal scale, (iv) dimensions of the available wood to be employed in the ELJs, as provided by the City of Sioux Falls, and (v) dimensions of the experimental apparatus (Wallerstein et al., 2001; Gallisdorfer et al., 2014). Given these data and qualifications, Table 1 summarizes the dimensions of the field prototype and the fixed-bed physical model (see Gallisdorfer et al. (2014) for additional details).

Table 1
Summary of prototype (Big Sioux River, SD) and model dimensions.

Parameter	Prototype	Model
Discharge Q ($m^3\ s^{-1}$)	51.1	0.0268
Top width (m)	40.5	1.9
Bottom width B (m)	40.5	1.9
Depth h (m)	2.2	0.114
Velocity u ($m\ s^{-1}$)	0.574	0.128
Bed slope S_B	0.00047	0.0005[a]
Bed texture (mm)	0.08 to 0.1	NA
Froude number Fr	0.124	0.124
Reynolds number Re	10^6	10^4

[a] Later corrected to 0.00005, based on bed shear stress calculations.

The experiments were conducted in a tilting, recirculating (open loop) flume, 1.9 m wide, 7 m long, and 0.5 m deep with 90° fixed banks (Fig. 1). Three sump pumps were operated in parallel to deliver a maximum discharge of 0.0268 m^3/s, monitored using an in-line flow meter, and this discharge corresponds to the 1.48-year return period within the prototype (which is close to the target design discharge of $Q_{1.5}$; Gallisdorfer et al., 2014). The 6-inch inflow pipe was buried into a 2.0-m-wide, 0.9-m-deep, and 0.9-m-tall headbox filled with cobbles, which dissipated all pump-related turbulence. Fifteen flow straighteners, 0.20 m tall and 0.37 m deep, were installed evenly across the entrance to the flume and downstream of the headbox, and ten adjustable vertical vanes 0.16 m wide and 0.26 m tall were installed at the flume exit to regulate flow depth within the flume. Vertical profiles of velocity and at-a-point depth measurements along and across the test section of the flume confirmed uniform flow conditions (described below). Flume slope was adjusted manually and checked using a rod and level (elevation resolution is ± 1 mm).

Two ELJ structures were employed, referred to as ELJ-1 and ELJ-2 (Fig. 2). These structures are slightly modified versions of a bank-attached deflector jam commonly used in field applications (Brooks et al., 2006). These ELJ types were chosen to examine the effect of structure shape and penetration distance on the flow field and drag forces. Element dimensions used in the ELJs were scaled based on the width ratio of prototype-to-flume and available wood (Gallisdorfer et al., 2014). Each structure included five layers of wooden elements: three layers of key elements with a diameter of 0.032 m; and two layers of notched, cross-spanning elements with an effective diameter of 0.019 m. All elements exposed to the flow (upstream and cross-stream) had simulated wooden root wads attached: disks 0.063 m in diameter and 0.014 m thick. Penetration distances into the flow were 0.40 m (0.21B) for ELJ-1 and 0.28 m (0.15B) for ELJ-2, corresponding to respective values of 8.5 and 6.1 m for the prototype. The differences between these two structures are overall size and orientation and the penetration distance into the flow. In the field, such ELJ structures would be fixed in place (immobile) and ballasted or backfilled with gravel and cobbles (Brooks et al., 2006).

Downstream (drag) and cross-stream (transverse) forces acting on a single ELJ were measured at 240 Hz by a Futek MBA400 biaxial load cell, which has a dynamic range of 230 N and a resolution of 0.03 N. This load cell was carefully calibrated in situ using fully saturated and submerged ELJs and a precise force scale with a range of 0 to 5 N. Forces were measured for the entire structure, given that all members were interconnected and fixed in place; and the ELJ was mounted to the load cell at a single location (Fig. 2E). The instrumented ELJ was suspended pendant to flow with about a 2-mm gap between the bed and wall of the flume. All forces reported here are based on 180-s time averages.

Experiments considered both single- and multiple-structure installations. Fifteen different configurations were examined, each employing a specific number of structures and collecting specific data. For each configuration using more than one ELJ, one or more experimental runs were conducted in which ELJ spacing was varied. For all runs with an ELJ, an instrumented structure was deployed at a fixed location 4.6 m downstream of the headbox. One or two additional ELJ structures of the same type would be installed either upstream or downstream of the instrumented structure on the same side of the channel. Center-to-center spacing between these structures is reported. Table 2 summarizes each configuration and the data collected.

Flow velocities were collected using a side-looking Nortek Vectrino II acoustic Doppler velocimeter (ADV). Vertical profiles of fluctuating velocities in the downstream u (x-direction; positive in the downstream direction), vertical v (y-direction; positive upward), and cross-stream w (z-direction; positive toward the left bank looking downstream). Velocity data were collected across the entire cross section and in the near-field surrounding the ELJ. For the cross sections, data were obtained in 24 vertical profiles spaced 0.05 to 0.1 m across the flume, and each profile contained 11 sampling locations spaced at intervals of 0.01 to 0.02 m

Download English Version:

https://daneshyari.com/en/article/6432046

Download Persian Version:

https://daneshyari.com/article/6432046

Daneshyari.com