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# River scale model of a training dam using lightweight granulates

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**Abstract**

Replacing existing river groynes with longitudinal training dams is considered as a promising flood mitigation measure in the main Dutch rivers, which can also serve to guarantee navigability during low flows and to create conditions favourable for ecological development. Whereas the bed response in the streamwise uniform part of a river trained by a longitudinal dam can be readily predicted, the bed response at the transition zones is unclear. In the present study, we investigate the local morphological effects resulting at the intake section of a longitudinal training dam, where the flow is distributed over the main channel and a side channel in between the dam and the river shore. A sediment recirculating model with a nearly undistorted geometry with respect to the prototype was setup. Lightweight polystyrene granulates were used as a surrogate for sediment, to properly scale the Shields parameter without compromising Froude scaling, and reach dynamical similarity. A laser scanner allowed collecting high-resolution bed elevation data. Results obtained under typical low flow and high flow conditions show a general deepening of the bed in the area adjacent to the training dam, in response to narrowing of the main channel. Scour at an upstream river groyne embedded in the model showed a scour hole which was deeper than realistic. Throughout the entire domain, bedforms developed featuring geometrical properties that reproduced the prototype conditions appropriately. Based on a comparison with characteristics from the River Waal, regarded as the prototype without a longitudinal dam, lightweight sediments were considered to be a proper choice for this study, in which bedload is the main sediment transport mode. The main conclusion regards the absence of significant morphodynamic developments at the intake section, both during the high flow experiment and during the low flow experiment, which can be attributed to the alignment of the dam with the local streamlines.


*Keywords:* Flood mitigation; Physical scale model; Lightweight granulates; Training dam; Groynes; River Waal

## 1. Introduction

Longitudinal training dams (Fig. 1) serve to constrict the flow in the navigable part of the river during low water conditions, while preserving a high cross-sectional area, and therefore a high channel conveyance during high water conditions. In The Netherlands, replacement of a series of river groynes (also referred to as spur-dikes, or wing dams) by a longitudinal dam is considered to be a promising flood mitigation measure. Next to the benefits related both to low flows and peak water levels, training dams are expected to exert a favourable influence on ecological conditions near the riverbanks, where flow velocity will decrease and the effect of ship waves will diminish.

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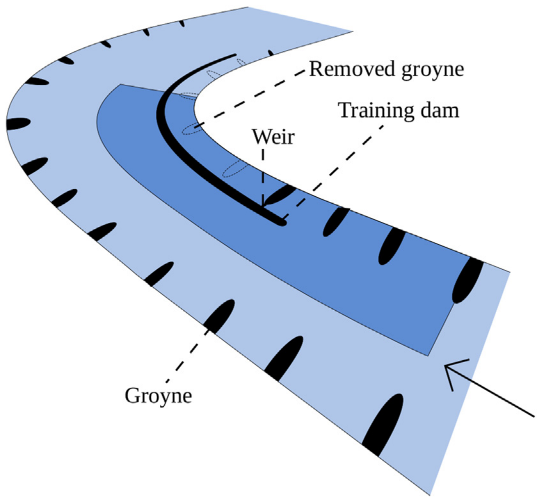


Fig. 1. Sketch of the prototype. Dark area corresponds to the area included in the physical scale model.

The riverbed can locally aggrade or degrade due to the three-dimensional flow patterns around the training dam, especially at the upstream head of the dam. Flow impinging on the head and separation of the flow may induce local scouring and sedimentation, which may lead to undermining of the structure or to impediment of navigation, respectively. In the present contribution, we focus on local morphological effects in response to flow velocity patterns in the surroundings of a longitudinal training dam, based on experiments with a physical scale model with a moveable bed.

Several studies (e.g. Ettema and Muste, 2004; Kuhnle et al., 1999, 2002; Yossef and de Vriend, 2010) have analysed the effect of groynes on flow patterns and bed morphology. For example, Ettema and Muste (2004) have systematically analysed the influence of several scaling ratios on geometrical descriptors of scour occurring behind a groyne. Similar studies on the effect of longitudinal training dams are scarce (Westrich, 1988). The complex three-dimensional character of the flow around river training works renders numerical modelling a daunting task, which is why a laboratory approach is still being adopted, despite it being labour intensive. Physical-scale models with movable beds primarily rely on scaling of the Shields parameter, which is the non-dimensional bed shear stress quantifying the mobility of the sediment. Because sediment properties cannot easily be manipulated, dynamic similarity of the flow is not always achieved. Ettema and Muste (2004) show that scaling based on shear stress leads to a much higher Froude number in the model, which significantly influences the resulting morphology. A way of circumventing this is to use lightweight sediments that magnify the mobility. Despite potential drawbacks of lightweight sediments related to buoyancy, the angle of repose, skin friction and bed-form shapes (Frostick et al., 2011), the use of low-density surrogates for sediment may be considered one of the few options to achieve dynamical similarity of both sediment transport and the basic characteristics of the mean flow in a physical scale model.

In this study, we employ lightweight sediments to study the local morphological response to flow variation at the upstream intake of a longitudinal training dam, where flow divided over the main channel and a side channel in between the dam and the river shore. In Section 2, we analyse the most relevant parameters using dimensional analysis. In Section 3 we describe the design of the experiments and in Section 4 we present the results. These results, and the suitability of polystyrene granulates for this type of study, are discussed in Section 5 and main conclusions are drawn in Section 6.

## 2. Dimensional analysis

We determine a set of dimensionless parameters characterizing the main processes in the flume by dimensional analysis. The following variables characterize flow, sediment transport and morphology:

$$L,\ W,\ d,\ D_{50},\ \rho_w,\ \rho_s,\ \rho_s-\rho_w,\ \nu,\ s,\ g,\ C \text{ and } U,$$

which represent a characteristic length, width and depth (m), median particle diameter (m), density of water (kg m$^{-3}$), difference between sediment density and water density (kg m$^{-3}$), kinematic viscosity (m$^2$ s$^{-1}$), surface tension (kg s$^{-2}$), gravitational acceleration (m s$^{-2}$), the Chézy friction parameter (m$^{0.5}$ s$^{-1}$) and a characteristic velocity (m s$^{-1}$). We reduce this set of variables to a set of non-dimensional variables through dimensional analysis:

$$L_*,\ W_*,\ D_{50*},\ \Delta,\ Re,\ We,\ Fr,\ S_0,$$

in which:

$$L_*=L/d,\ W_*=W/d,\ D_{50*}=D_{50}/d,\ \Delta=(\rho_s-\rho_w)/\rho_w,$$
$$Re=Ud/\nu,\ We=\rho_w U^2 d/\sigma,\ Fr=U/(gd)^{0.5},\ S_0=U^2/\left(C^2 d\right)$$

The first three terms can be used to achieve geometric similarity. The other terms need to be equal in the model and in the prototype to achieve dynamic similarity. The submerged density of the sediment ($\Delta$) represents the ratio of gravity and buoyancy (lift), the Reynolds number ($Re$) the ratio between inertia and viscosity, the Weber number ($We$) the ratio between inertia and surface tension, the Froude number ($Fr$) the ratio between inertia and gravity, and the equilibrium slope ($S_0$) is the balance between gravity and drag.

From this set, we can obtain the dimensionless particle number $D_*$ (van Rijn, 1984a), the shields parameter $\theta$ (Engelund and Hansen, 1967), and the interaction parameter $\gamma$ defined as (Struiksma et al., 1985):

$$D_*=\Delta^{1/3}Re^{2/3}Fr^{-2/3}D_{50*}=D_{50}\left(\Delta g/\nu^2\right)^{1/3},$$
$$\theta=S_0(D_{50*}\Delta)^{-1}=U^2/(C^2\Delta D_{50}),$$
$$\gamma=2\left(\Delta D_{50*}S_0^3\right)^{-1}(W_*/Fr)^2=2(UgW^2)/\left(C^3d^2(\Delta D_{50})^{0.5}\right)$$

The dimensionless particle number represents the relation between the combined effect of gravity and buoyancy, and viscosity. Based on this parameter, it is possible to predict the bed-form regime (van Rijn, 1984b). The Shields parameter