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# A design method for a debris flow water-sediment separation structure

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ABSTRACT

Debris flows, which contain many coarse particles, usually have significant destructive power and, therefore, controlling the coarse fraction is an important approach to reducing destruction. A new herringbone structure has been designed to separate coarse sediment from water in debris flows. The effectiveness of this structure is influenced by the design dimensions which include: the height of draining dyke, the size of overflow gate in the draining dyke, the length of herringbone water-sediment separation grid, the width of the grid, the gradient of the grid, the intersection angle between ribbed beams and ridge beam, and the height and longitudinal gradient of outflow channel. Using theoretical analysis and model experiments, a design method for the determination of these dimensional parameters is presented. Based on this method, the structural design procedure that may be used directly in engineering design has been developed.



## 1. Introduction

Debris flows are a common geological hazard in mountainous areas. Those that contain coarse particles have significant destructive power and reducing this coarse content is an important approach to mitigating damage in disaster situations (Fei and Shu, 2004; He et al., 2007; Chen et al., 2015). Open dams, including slit dams, grid dams, flexible barriers and debris flow brake (Huebl and Fiebiger, 2005; Mizuyama, 2008; Takahara and Matsumura, 2008; Brighentia et al., 2013; Brunkal and Santi, 2016), are a primary way to separate coarse sediment, which often lose their water–sediment separation function because of blockage by sediment and other debris (Xie et al., 2014a). Therefore, a new herringbone water-sediment separation grid has been developed to remove coarse particles from debris flows (Xie et al., 2014a). It consists of a draining dyke, a herringbone water-sediment separation grid, an outflow channel and deposit fields (Fig. 1). When a debris flow enters the grid, particles larger than the grid openings are separated, and slide into deposit fields from the grid surface, while the residual material enters the outflow channel. Xie et al. (2014a) conducted a series of model experiments to test the effectiveness of the new structure. Greater than 80% of the removed coarse particles slide into the deposit field, leaving the grid surface open and available for water-sediment separation in subsequent debris flows and thus addressing a shortcoming of other water-sediment structures. The model experiments also demonstrated that the structure is most effective in debris flows with a bulk density of less than 1900 kg/m$^3$ (Xie et al., 2014b) and that it may be used to effectively separate logs and other vegetative debris (Xie et al., 2016c). However, to optimize the separation effect for practical engineering, the structure dimensions must be carefully designed. Using theoretical analyses and model experiments, this paper presents a design method for structural dimensions, including the height of the draining dyke, the size of the overflow gate in the draining dyke, the width, length and gradient of the water-sediment separation grid, the intersection angle between ribbed beams and ridge beam, and the height and gradient of the outflow channel.

## 2. Structural dimensions

### 2.1. The draining dyke

The draining dyke is set in the channel and is similar to a traditional check dam. Its purpose is to guide the debris flow to the herringbone water-sediment separation grid and to provide enough height to facilitate the movement of separated sediment off the grid and thereby initiate the separation function. Therefore, the height and overflow gate dimensions of the draining dyke must be designed carefully. The design of other structural dimensions, including crest width, bottom width, energy dissipation works, etc. follow from those of the draining dyke (Zhou et al., 1991).

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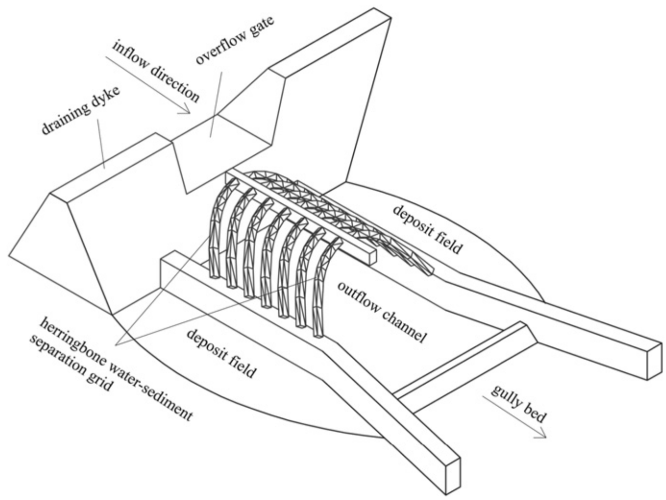


**Fig. 1.** The herringbone water–sediment separation structure.

### 2.1.1. The draining dyke height

The draining dyke height is related with the height of water-sediment separation grid. It can be calculated by the following formula:

$$H_1 = h + H + h_2 + \Delta h \tag{1}$$

where $H_1$ is the height of the draining dyke (m), $H$ is the vertical height of ribbed beam in water-sediment separation grid (m), $h$ is overflow depth (m), $h_2$ is the side wall height of the outflow channel (m), and $\Delta h$ is the free board of the draining dyke (m). The suggested free board is 0.5– 1.0 m.

### 2.1.2. The overflow gate dimensions

The overflow gate directs the debris flow to the water-sediment separation grid from debris flow gully bed. Its dimensions, including height and width, are related with the debris flow design discharge. Based on the energy equation of hydrodynamics, Lin et al. (2015) developed a formula for the calculation of the discharge capacity of the overflow gate (Formula (2)).

$$Q_c = \lambda C(5b + 4mh)h^{3/2} \tag{2}$$

where $Q_c$ is debris flow discharge ($m^3$/s), $\lambda$ is a correction factor (when the overflow gate is located on the center line of the debris flow gully, $\lambda$ is 1; otherwise $\lambda$ is 0.75– 0.8), $b$ is the basal width of the overflow gate (m), $m$ is a coefficient indicating the incline degree of the overflow gate ($m = \cot\beta$, $\beta$ is the gradient of the overflow gate), the suggested value for $m$ is 0, $h$ is the overflow depth (m), and $C$ is a discharge coefficient, which can be calculated by the following formula.

$$C = -0.85\gamma_c + 0.02\alpha + 0.24(b/W) + 1.79 \tag{3}$$

where $\gamma_c$ is debris flow density before water-sediment separation (t/$m^3$), $\alpha$ is the gradient of gully bed (°), $W$ is the gully width (m).

Using these formulae, the calculation method for the overflow gate dimensions is as follows:

(1) Depending on the gully width $W$, the basal width of the overflow gate $b$ is estimated by engineering experience.

(2) The discharge coefficient $C$ is calculated by formula (3).

(3) Using the discharge coefficient $C$, debris flow design discharge $Q_c$, the basal width of the overflow gate $b$, and the coefficient $m$ in formula (2), the overflow depth $h$ is determined.

## 2.2. The water-sediment separation grid

For effective engineering applications, particles larger than the design separation diameter (opening width in the grid $D$ shown in Fig. 3) are removed from the debris flow and entered into the deposit fields. The residual debris flow material falls into the outflow channel. Thus, the following structural dimensions of the separation grid must be carefully designed.

### 2.2.1. Water-sediment separation grid length

Considering the separation function and construction cost, the water-sediment separation grid length $L$ (Fig. 3) is equal to the maximum debris flow motion distance along the grid. Assuming that the debris flow moves along the surface of the grid under the gravitational effect, the following formula may be used to calculate the design length of the grid.

$$L = v_x\sqrt{\frac{B}{g\ \sin\theta\ \cos\theta}} = \frac{Q_c}{(b + mh)h}\sqrt{\frac{B}{g\ \sin\theta\ \cos\theta}} \tag{4}$$

where $L$ is water-sediment separation grid length (m), $v_x$ is the velocity of debris flow moving through the overflow gate (m/s), $B$ is the grid width (m), $g$ is gravitational acceleration (m/$s^2$), $\theta$ is the grid gradient (°), $Q_c$ is the design discharge ($m^3$/s), $b$ is the basal width of the overflow gate (m), $m$ is the coefficient indicating incline degree of the overflow gate, $h$ is the overflow depth (m).

Using this formula, Xie et al. (2016a) conducted a series of model experiments to test its accuracy. The results showed that the experimental and calculated values for the grid length form a linear relationship allowing for a correction coefficient. Further analysis indicated that the correction coefficient changes with the bulk density of the debris flow. Therefore, a formula for determining the grid design length is derived from the theoretical formula, corrected using a coefficient related to the bulk density of the debris flow.

$$L = (2.131-0.49\gamma_c)\frac{Q_c}{(b + mh)h}\sqrt{\frac{B}{g\ \sin\theta\ \cos\theta}} \tag{5}$$

where $L$ is the water-sediment separation grid length (m), $\gamma_c$ is the debris flow density before water-sediment separation (t/$m^3$), $Q_c$ is the design discharge ($m^3$/s), $b$ is the basal width of overflow gate (m), $m$ is the coefficient indicating incline degree of the overflow gate, $h$ is the overflow depth (m), $B$ is the grid width (m), $g$ is gravitational acceleration (m/$s^2$), $\theta$ is the grid gradient (°).

### 2.2.2. Water-sediment separation grid width

As shown in Fig. 2, if the grid width $B$ is too small, the water–sediment separation process will complete inadequately. If $B$ is too large, the capacity of the deposit fields will be reduced. Meanwhile, debris

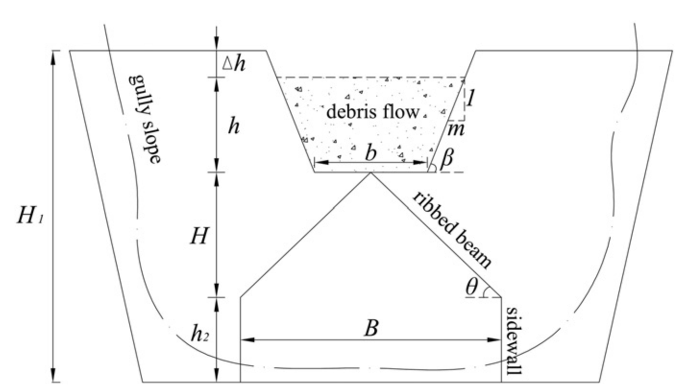


**Fig. 2.** Elevation view of herringbone water-sediment structure.