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# Characteristics of interactions among a row of submerged vanes in various shapes

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**Abstract**

The technique for simulating bed profile induced by submerged vanes so far has been limited to flat plates in the shape of a rectangle. In this study, we advanced the simulation technique to vanes with any shape. An innovative approach to take into account the boundary effects of channel banks, water surface, and channel bed was also proposed. A numerical model was developed to explore the influence of vane shapes on the induced transverse bed profiles. The extent of vane shapes on the interaction effect in a system of vanes was also investigated. Certain characteristics about submerged vanes in different shapes were observed and discussed, which might be of help for vane system design at preliminary stage.



*Keywords:* Submerged vane; Interaction; Vane shape; Panel method; Sediment management

## 1. Introduction

Submerged vane (Fig. 1) is a type of hydraulic structure for sediment management in alluvial channels. Vanes work by generating vortices downstream to alter the flow direction and the distribution of shear stress on channel bed, such that a transport of bed material in the transverse direction along the channel cross-section is induced, which, in turn, results in a modification in bed profile. With proper configuration on the vanes, favorable bed profiles can be achieved. As a mean for river management, submerged vane has been used in a wide range of applications, such as channel bank protections (Barkdoll, 2003; Johnson et al., 2001, 2003; Odgaard and Kennedy, 1983; Wang and Odgaard, 1993), sediment exclusion at water intakes (Barkdoll et al., 1999; Michell et al., 2006; Nakato and Ogden, 1998; Wang et al., 1996) and deepening channels for navigation (Odgaard and Spoljaric, 1986; Odgaard and Wang, 1991b). Many example field applications have been reported in Odgaard (2009).

The aim of this paper is to present recent progress in simulation technique for submerged vanes. The novelty of the present model is its ability to simulate vane arrays comprising vanes in any shapes, rather than just rectangular flat plats as in Ouyang et al. (2008) or just single vane as in Ouyang (2009). An innovative approach involving layers of mirrored image vanes to take into account the boundary effects of channel banks, water surface, and channel bed is also proposed, which to the authors' knowledge is the first time the effect of image vanes on the circulation around the real vanes is considered. In Ouyang et al. (2008), the vane-induced flow field was simply simulated using one bound vortex and one tip vortex for each of the vanes only. Although the model is capable of simulating the interaction between vanes in a multiple-vane system, however, due to the simplicity in flow simulations, it is limited to vanes only in shape of rectangular flat plate. Ouyang (2009) advanced the model by employing the Panel method in flow simulations, such that the shape of the vane is no longer limited to rectangular flat plate. However, the model is limited to a single vane only and is not applicable for vane arrays. Consequently, the focus of the study was on the performance of a single vane in various shapes without addressing the interaction effect which is a phenomenon only emerging in a multiple-vane system. In the present study, the model is further improved to vane arrays without the limitation of vanes in the shape of a rectangle as in Ouyang et al. (2008) or of a single vane only as in Ouyang (2009). The model is capable now to explore the effect of

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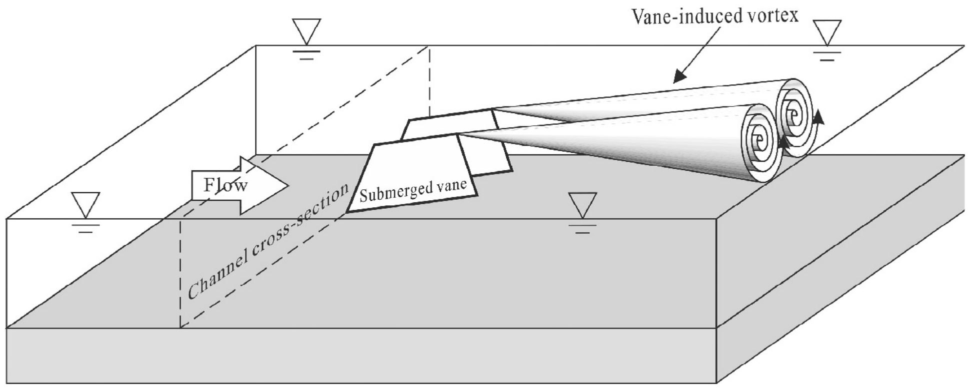


Fig. 1. Submerged vane system and the induced vortices.

different vane shapes on the induced bed profiles and the interactions between vanes, which are the topics investigated in the follow-up discussions presented in this paper. As a series of studies, we continued to explore the three types of vanes that have been studied by Ouyang (2009) for a single vane only. Here we extended the investigations to vane arrays to explore the influence of vane shapes on the resultant bed profiles and the interaction effects.

## 2. Literature review

The most notable researches on vanes are the series of theoretical deductions and experiments that were conducted by the Iowa Institute of Hydraulic Research (IIHR) in the last thirty years, including those by Odgaard and Kennedy (1983), Odgaard and Lee (1984), Odgaard and Mosconi (1987), Odgaard and Spoljaric (1986), and Odgaard and Wang (1991a, 1991b). Odgaard and Kennedy (1983) applied the wing theorem in aerodynamics to submerged vane research and successfully derived the relationship between bend flow and vane systems based on the balance of moment between the secondary current and the vane system. Odgaard and Mosconi (1987) then modified this equation by incorporating the lifting-line theory in aerodynamics into vane theory deductions. The equation they obtained could precisely estimate the influence of the aspect ratios of vanes (ratio of vane-height to vane-length) on flow training effects. Spoljaric (1988) further verified their theoretical results with flume experiments. Odgaard and Spoljaric (1986) extended the application of vanes to the deepening of navigation channels. Odgaard and Wang (1991a) employed the theorem of biplanes in aerodynamics to expand the theory of single vane to array systems with multiple vanes. Wang and Odgaard (1993) solved the momentum equation for one-dimensional bend flow, and deduced the required bed shear stress that each vane needs to generate to cancel out the secondary current. Ouyang et al. (2008) stated that the implicit assumption of equal circulation reduction among the vanes in the model of Odgaard and Wang (1991a) was not applicable for a system comprising more than two vanes in a row. They also improved Odgaard and Wang's theorem and developed a circulation reduction formula suitable for vane systems with unequal spacing. Ouyang (2009) utilized the panel method in wing theory to examine the flow training effects of single vanes in various shapes. He found that, for vanes with the same plate area, tapered and forward-swept shapes can enhance vane functionality.

In view of previous research on submerged vanes, the focus of most studies was on rectangular vanes due to simplification on the theory. Although Spoljaric (1988) and Ouyang (2009) explored the relationship between the shape and flow training effects of vanes, their results are limited to single vanes only. Little has been explored on vane arrays in shapes other than rectangle flat plate. Further studies in this aspect are required.

In the following section, the model of flow field and bed profile induced by a multi-vanes system in any shape was first developed. The model was then verified by comparing with experimental data in the literature. The developed model was used as a numerical tool to investigate the influence of vane shapes on the induced transverse bed profiles and the interaction effects between vanes. Discussions and conclusions were finally drawn based on the findings.

## 3. Theorem

### 3.1. Flow field induced by a row of vanes

In previous studies (Odgaard and Wang, 1991a; Ouyang et al., 2008), single bound vortices and wake vortices were used to simulate the flow fields created by the vanes. Although such simplified models can roughly represent the resulting flow field characteristics, they are only applicable to rectangular vanes. To investigate the interaction effects among vanes in other shapes, we adopted the panel method of the wing theorem for flow field simulation. Ouyang (2009) has used this method to simulate the flow field induced by a single vane. Although applicable for single vanes in various shapes, the model is however limited to one single vane only. Here we extend this technique to vane system comprising multiple vanes in a row.

Considering a row of vanes set in parallel with an angle of $\alpha$ to the flow and installed along the channel cross-section, as illustrated in Fig. 2. By using the panel method, each of the vanes is segmented into a number of panels. The length and height of the panel, denoted as $\Delta x$ and $\Delta y$ respectively, are related to the number of panels used in numerical calculations, which are yet to be determined by numerical experiments

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