Sediment Control At The Lateral Channel Inlet

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Abstract. Environmental and civil engineering projects frequently employ the open channel side intake structure. However, the commonest among the issues faced in most of the lateral intakes include sedimentation and sediment delivery. This involves several problems namely, decreased flow discharge capacity in the irrigation canals and the threat of water blockage during times of low water flow. Besides, this problem with the sediment either lowers the performance levels or causes failure of the facilities that this sub-channel serves. Hence, the engineers focused on designing an intake with the features of high flow discharge and low sediment delivery. This paper attempts to review and summarize the literature relevant to the branching channel flow and submerged vane technique to minimize the sediment-related issues. The present review highlights that most of the earlier research work done dealt with the characteristics of the flow in a right-angle branch channel possessing rigid confines. Also, more investigations are required regarding the implications of the submerged vanes. Besides, no comprehensive studies are available on the saddle point itself, and a high percentage of the studies have been part of earlier investigations that had focused on only briefly outlining this subject.

Keywords: Sediment, lateral channel, Separation zone, Submerged vanes.

1. Introduction

A branching channel signifies any lateral water diversion from open channels or rivers. In several practical enterprises, these branching channels are very useful, particularly in the irrigation network, drainage systems, and many other water resource projects [1,2]. Intake channel flow has a substantial propensity to deviate the sediment towards the lateral branch [3]. In the open channel, the most important and complex issues to be resolved are sediment transport and deposition [4]. As the entry and deposition of the intake sediments cause damage to the installation facilities served by this intake, the maintenance costs escalate. However, the sediment entering the farms lowers the soil quality. Therefore, the flow and stream conditions, as well as the characteristics of the system need to be focused upon while studying the impacts of the flow intrusion and hydraulic structures [5]. Many theoretical, experimental, and numerical studies on side open channels have been conducted over the recent decades to grasp the characteristics of such branching flows.

Clear elucidation of this phenomenon becomes a challenge because the branching flows are very complex and include multiple interlink variables [6]. When the intake structures are diverted, some portion of the river flow may induce the hydraulic conditions of the flow to experience certain changes at the inlet, which may include alterations in the diversion discharge, water depth, water surface, and hydraulic jump, separation zones, stagnation point, contraction coefficient, energy head, energy loss coefficient, and power, etc. [2]. During the transverse flow, some part of the river water gets diverted into the branch channel in a sort of a curved flow [7]. The deviation of the streamlines near the lateral
intake causes the formation of a few vortices, pressure gradients, shear, and centrifugal forces. At the intake, the flow separation and secondary movement which are caused, induce local scouring and sedimentation [4]. Near the bed region, the directions of the velocity vector show significant differences from those at the surface. The formation of secondary circulation is observed, similar to the one present in the bend flows, due to this change in the velocity profile. Secondary circulation takes place because the surface water, which moves faster uses greater power to swirl than water close the channel bed, which moves at a slower rate, just like the bend flows [8]. Significantly, centrifugal forces are the same that observed in the flow of the bent channel. Consequently, at the intake entrance, the huge zone of separation along the upstream section of the diversion bank is the most prominent feature. The flow in this area revealed the characteristic low velocity, eddies, and recirculation. Due to the high momentum entry of the flow into the branch channel in the direction of the flow in the main channel, this area of separation is detected. Furthermore, the separation zone size is greater at the free surface than it is at the bottom. It is evident that as the boundary shear stress and flow velocity rise, the sediment-transport capability and erosion capacity of a flow also increases. The vertical gradient of the streamwise velocity interacts with the primary flow curvature to produce a type of helical or secondary flow in the channel bend flow, thereby inducing greater depths and velocities near the outer (concave) bank [9]. The deepening of the channel causes an undermining of this bank and as the larger local velocity hits it, the degree of erosion of the river bank rises [12]. Anything that prevents secondary flows and eddies downstream the intake inlet and the separation zone at the internal intake bank lowers the entry and accumulation of sediment in the sub-channel [7]. Figure 1 shows the turbulent flow and eddies formed at the lateral intake.

Several research works have been conducted on a variety of components of the side channels, as well as the repercussions of the alterations in many different parameters, namely channel dimensions, inclination angle, and diversion ratio. Besides, many mechanisms have been employed to manage the diverted outflow and sediment entry into this sub-channel, and the use of submerged vanes has shown to be the most practical and economical of them all. In this review paper, several studies on diversion channels for various flow conditions and sediment control at these channels have been summarized, with the emphasis on a few processes and methods that boost the flow diversion by reducing the entry and deposition of the sediment at the entry point of the lateral channel.

2. Sediment Characteristics

2.1. Introduction

Sediment is defined as the solid particles or debris transported in fluid media or identified in deposits post transportation by the action of flowing water, wind, wave, glacier, and gravity [13]. Thus, sediment transport research is concerned with the interaction between moving sediment particles and water. Sediments reveal characteristics based on individual particles. Hence, to predict sediment movement, one needs to understand the physical properties of the sediment particles. The two types of sediment properties that can be distinguished include individual and bulk characteristics. As the number of characteristics describing these aspects is quite high, figure 3 lists the commonest and most essential features, as well as their parameters.

2.2. River Sediment Transport

As water flows, solid particles can be entrained over a movable bed. Due to the interaction between the water and sediment, the mixture gets displaced in the watercourse. Thus, the primary source of the sediment load material comes from the material erosion in a catchment region. Besides, the collapse of the earth can augment the sediment load of a flow. Thus, sediment arising from erosion of the catchment is now present for transportation by the water stream. The sediment is also carried by the material of the riverbed that is moved by the stream's shear force. The quantity of the sediment will alter along the reach and is determined largely by the catchment factors and the distance between the reach and the sediment source. However, other factors like sediment amount, flow discharge, channel
slope, and catchment and channel features also affect the quantity of the sediment load being carried [14].

2.2.1. Bed-Load. The passage of sediment in a river is defined as bed-load transport when the sediment particles exhibit rolling, sliding, or at times jumping motion along the channel bed. The occurrence of bed-load is evident when shear stress surplus is found at a low level. In general, this is a movement where the individual particles exhibit intermittent motion when in contact with the river bed [15]. The critical shear stress produced by the particles in contact with the river bed needs to be transcended by the water forces striking on each particle. The smaller and lighter particles possess lower critical shear stress; therefore, as they need lower force to transfer, they will be the first to exhibit motion [16]. The standard range for a normal river is a bed-load transportation rate of (5–25)% of suspended particles [15].

2.2.2. Suspended Load. With any escalation in the shear stress excess, a corresponding rise is observed in the degree of turbulence caused in the bed and its upward movement, until a point is reached when the particles from the bed are displaced and remain in suspension. Apart from this, the upward diffusion of the turbulence favors particle suspension, regardless of gravity [14].

2.2.3. Wash Load. Wash load transport is concerned largely with moving very small particles of clay and silt. The overland flow carries these particles into streams, washing them off the land, so that they very rarely accumulate in large quantities in the bed material. During transit, the abrasion of the silt particles can produce a wash load. On the contrary, in the case of a suspended load, a part of the wash load becomes independent of the factors of the streamflow hydraulics. Through Brownian motion, the very tiny particles, notably fine clay, can remain suspended even in motionless water [14].

2.2.4. Total Load. The total sediment load is, therefore, the sum of the bed-load, suspended-load, and wash-load sediments. Largely, it is the total load that can be estimated if the sediment load generated by each sediment transport mechanism is known. The total load, on the other hand, is determined using the total load formulae provided by the same authors in a number of well-known sediment transport formulas, including Bagnold [17], Engelund and Hansen [18], and Ackers and White [19].

The pathways and origins of sediment movement are depicted in figure 2 [14].

![Figure 1. Vortices formed at the lateral channel junction [11]](image1)

![Figure 2. Components of sediment transport [14].](image2)

During conditions of normal flow, all the tiny particles that may have been present in a particular riverbed will have been completely carried away. The smallest size of the remaining particles is defined by the critical shear stress and is linked to the flow velocity. Bed armoring is noted when no particles smaller than a specific size are observed [20].
In a stream, when the bed has a greater width than the flow depth, the bed shear stress ($\tau_b$) can be assumed to equal the mean shear stress ($\tau_0$), and the hydraulic radius ($R$) can be assumed to equal the flow depth ($y_0$). When particle velocity achieves its limit, the average bed shear stress is equal to the critical shear stress of the particle ($\tau_{cr}$):

$$\tau_{cr} = \tau_0 = \rho g y_0 S_0$$  \hspace{1cm} (1)

Where $\rho$ is the fluid density, $g$ refers to gravity, and $S_0$ indicates the bed slope.

The theoretical reference value for critical friction velocity ($u_{*c}$) is derived from the bed shear stress:

$$u_{*c} = \sqrt{\tau_0 / \rho} = \sqrt{g y_0 S_0}$$  \hspace{1cm} (2)

The Shields diagram is combined with the entrainment function ($F_S$) to determine whether particle motion will take place [20].

$$F_S = \frac{\tau_{cr}}{(\rho_s - \rho) g D}$$  \hspace{1cm} (3)

Where $\rho_s$ refers to the sediment particle density, and $D$ indicates particle diameter.

In Figure 4 the Shields diagram is evident, in which the entrainment function is graphically depicted versus a type of Reynolds number called the shear Reynolds number ($Re_*$) to show the threshold of motion. The fluid velocity term in the shear Reynolds number is the friction velocity ($u_*$) [21].

$$Re_* = \frac{u_* D}{v}$$ \hspace{1cm} (4)

The Shields function is the curve visible on the Shields diagram, indicative of the particle motion threshold. The coordinates of the entrainment function and shear Reynolds number that are plotted beneath the Shields function are stable, but those mapped above the function are displaced.

**Figure 3.** A schematic representation showing the characteristics of the sediment and their parameters.
2.3. Sediment transport into a lateral channel
The fluvial open channel diversion systems exert a crucial impact on human activities. A comprehensive study of the complex flow structure and the dynamics of sediment behavior in the entrance of the lateral channel play a significant part in satisfying the earlier stipulated goals namely, diverted discharge, extended diversion channel lifetime, and decreased sediment transport into the side channel [22].

The spots where a river separates into two distinguishable channels that transport a portion of the flow and its material downstream are called fluvial bifurcations. Both the downstream rivers can either recombine at a confluence or flow separately to their outlets into the sea. Such river diversions are either natural or can be deliberately constructed. Diversions or lateral intakes are observed where one downstream branch flows away laterally, whereas the other continues down the same path taken by the inflow channel, from a geometrical perspective.

The diversion is indicated by a considerable proclivity of the sediment to travel towards the lateral branch [6]. The presence of centrifugal and shear forces induced by the curvature of the streamlines causes the formation of a spiral flow in the diversion channel [20]. The sediments are thus transported via the spiral flow from the riverbed to the diversion canal. The secondary current strength within the channel enables the significance of this phenomenon to be assessed [22]. The entry and deposition of the intake sediments cause some damage to the installation facilities served by this intake and thus raise the maintenance costs.

3. Latest techniques to solve sediment problems
Over the past few years, many techniques to lower the quantity of sediment entering into the intake channel have been developed and applied. One way of overcoming this problem is to change or alter the geometry of the intake channel, by implementing an appropriate diversion angle and the geometry of the intake inlet [23]. Besides, specific structures such as a skimming wall, spur dike, and submerged vanes which are installed at the channel entrance have been designed and developed to minimize the issue of sedimentation and sediment entry.

3.1. Submerged Vanes
Submerged vanes which have emerged as a rather recent strategy are effective in decreasing the sediment-related problems in rivers, particularly in the curved and branch channels [24]. To date, wood, concrete, and sheet piling have all been utilized as prototype vane materials. Further, in many systems, reinforced concrete is employed as the vane material.

Vanes have found wide usage in minimizing the transportation of bed sediment into the diversions, particularly the riverside water intakes for hydropower and municipal water supply use and a variety
of projects [25]. This technique exerts a good influence on the climate. However, the performance of the submerged vanes is affected by several factors. The Iowa vanes are employed to adjust the flow pattern near the bed, movement of the sediment downstream, specifically at the lateral flow of the rivers [26].

3.1.1. Theory. It was Odgaard and Wang [25,27] who proposed the basis of the design of the vane technique. Repliant upon the angle of installation, the flow pattern triggers a secondary vortex around the submerged vane, inducing changes in the pattern of the velocity distribution, thus altering the trend of sediment transfer [12]. As the water flow moves past the submerged vane, a pressure difference arises on both sides of the vane, causing a secondary flow after it (Figure 5) [28,29]. In figure 6 the clearly shown parameters include the initial vane height (H_0), the ratio of the vane height to vane length (H_0/L), angle of incidence, vane submergence (T), longitudinal and transverse vane spacing (δs), and (δn), respectively, and the distance between the outer vane and bank (δb).

\[
\Delta h = \frac{Q_i}{Q_b} d_b
\]

Where \( Q_b \) and \( d_b \) represent, respectively, the discharge and depth in the vane-generated near-shore channel at the upstream of the intake, and \( \Delta h \) indicates the rise in the bed level (decrease in the flow depth) outside of the vane field. At the downstream end of the intake, ingestion of the sediment may occur if \( \Delta h \) is adequate to increase the bed surface level to the sill of the intake [31].

3.1.2. Parameters affecting the performance of the vanes. If the submerged vanes (flow-training devices) are strategically installed, they can encourage mid-depth and near-surface flows to enter into the intake, while at the same time blocking the bedload transport from flowing into the intake.
channels. Many parameters affect the vane performance, including the ratio of the vane height to flow depth, the longitudinal distance between the vanes, vane angle to flow direction, and the distance of the first row of vanes from the bank [32]. Many investigations have been done on several aspects of the vane design to ensure sediment control at the intake. The studies include those of Nakato [33], Odgaard [31], Wang et al., [34], Barkdoll et al., [35], Tan et al., [36] and Moghadam et al. [37].

3.1.2.1. Arrangement of the Vanes. While designing the vane process, attention must be paid to the installation techniques. Vanes having 20° to 30° of an installation angle were noted to most highly affect the maximum normalized tangential velocity fluctuation throughout the course of the main channel; however, when the installation angle of the vane exceeds 40 degrees it is not recommended [38]. This performance of the vane is restricted to within the desired level when the angle of attack of the vanes is within ±3 degrees of the design angle and the linear dimensions fall within 10% of the design dimensions, in accordance to field experience [31].

3.1.2.2. Shape and dimensions of the vanes. The effectiveness of the submerged vanes is determined by their number, shape, size, and configuration. The influence exerted by a plethora of parameters that show efficacy in sedimentation in the intake zone must be noted when the optimum values for the size or configuration of the vanes is to be ascertained [39]. In the first step of designing the submerged vanes at the water intake points, the downstream tube generated by the dividing surface and bank line must be identified (Eq. 6). The inner row of vanes should be spaced far enough apart from the stream tube to prevent any suspended bedload from entering the intake and instead of passing through it.

\[
\frac{b_s}{b} = \frac{Q_i}{Q} 
\]

Where \( b \) indicates the width of the main channel, \( Q \) refers to the main channel discharge, and \( Q_i \) is the discharge in the diversion or intake. Ideally, this breadth (\( b_s \)) should be much less than the vane-to-bank distance (\( \delta b \)). In this case, the flow in the channel between the vanes and bank would be sufficient not just to deliver the flow required into the intake, but also adequate to ensure sediment transport beyond the intake [31].

Several researchers examined the features of vane design to control the sediment entry at the intake structures. Mirzaei et al., [39] investigated to determine the correct dimensions of submerged vanes placed in front of a 90° intake from a straight channel. Optimization was performed using Fuzzy TOPSIS, a multi-objective optimization technique where ten parameters were considered. In the simulations, three discharge ratios (11%, 16%, and 21%) were used. From the results, it is evident that for the submerged vanes in front of the lateral intakes from straight channels, the acceptable parameters include a height of 0.2 times the flow depth and a length of four times the vane height [39]. The recommendations of Odgaard [31] are considered the standard dimensions for the design and layout of the vanes. These dimensions were developed using prior experiences. In Table 1, the standard vane parameters are shown; site-specific constraints may necessitate changes in those measurements.

| Variables | Parameters |
|-----------|------------|
| \( H_v \) | 0.2–0.4d_s (generally 1–3 m) |
| Vane’s thickness | 0.05–0.20 m |
| \( L \) | 3 H_v |
| \( \delta_n \) | 3 H_v |
| \( \delta_s \) | 10–30 H_v |
| \( \delta_b \) | 3 H_v |
| \( \alpha \) | 10°–20° |
Where: \((H_v)\) is Vane height, \((\delta_b)\) The displacement between the first row of the vanes to the main channel sidewall, \((\delta_s)\) indicates the longitudinal spacing between the two successive vanes, \((L)\) refers to the length of the vane, \((\delta_n)\) is the transverse spacing between the vanes, and \((\alpha)\) is the angle of vanes to flow direction.

If the vane height is limited due to either navigation or other river characteristics, the lateral and longitudinal spacing may need to be reduced. The local environment strongly affects the distance to the bank or intake. Therefore, this distance can be determined only after careful examination of the upstream approach-flow patterns, especially those along the bank directly upstream from the vane field [31].

4. The effects of flow characteristics and submerged vane installation on sediment behavior at lateral channel

4.1. Separation zone

In the case of the diversion channel, the greatest challenge faced is channel blockage and restricted capacity caused by the sedimentation at its entry point. It is the vortex region that determines the practical width for the passage of the flow because the sediments are deposited in this vortex region at the entry point of the diversion channel as indicated in figures 8 & 9. Therefore, identification of the vortex area or flow separation region, as it is also termed, becomes imperative. In Figure 6, a schematic representation of a vortex region is seen, where the \(L_v\) and \(W_v\) indicate the length and width, respectively. It is noteworthy that the size of this area alters with depth; therefore, at the surface, it is bigger in size than it is near the bed [22].

Separation zones are created by the low flow velocity and water recirculation in the same location [20]. These zones encircle the recirculating water flow [40]. In these zones, the low velocity causes the formation of a sedimentation region [41, 42], which offers fish and plants a favorable habitat [43]. In figure 8, two major separation zones are presented [2]. The flow separation zones are influenced by the discharge ratio (ratio of the intake discharge to the inlet discharge), the angle formed by the lateral channel with the direction of the main channel flow, as well as the size of the submerged vanes installed[44]. The discharge ratio affects the location and size of just this separation region. As the discharge ratio rises, the size of this zone shrinks [45,46]. In fact, as the angle of lateral intake decreases the length of the vertical vortex (separation zone) increases; however, the width of the separation zone gets reduced [40].

Figure 7. A Diagram showing the stream tube of flow accessing the intake [31].

Figure 8. Zones of separation and stagnation point in the branching channel system [47].
The general method of decreasing the size of the separation region is by installing the vanes in front of the lateral channel inlet [44]. As vanes function based on the distribution of velocity non-uniformity in the branch channel, the use of submerged vanes causes this zone to lengthen [48].

4.2. Saddle point
A saddle point constructed in the downstream portion of the intake channel exerts one of the major impacts on the transportation of the sediments that get accumulated just before the point of the side-channel entry into the lateral channel [31]. The water particles show a downward tilt caused by the collision of the downstream flow corner of the intake entry. When this flow combines with the secondary flows, the saddle point is created. The interaction between the secondary current at the intake port, (described above as the continuous downward flow), and the secondary flow inside the main channel, all go towards the formation of the saddle point. The presence of the secondary flow at the mouth of the intake creates a part of the bedload presented at the downstream corner of the intake entry point to get diverted towards the interior of the intake, thus contributing to the formation of the return flows (Figure 10).

![Figure 9. Schematic view of the swirls formed in the diversion channel [23].](image)

![Figure 10. Saddle point position and return flow [50].](image)

To date, no complete or comprehensive studies are available on the saddle point. A large percentage of the researches done has been included in earlier studies that merely offered a brief description of this subject. If the submerged vane structures are installed in front of the lateral channel, they will affect the saddle point, where the intake ratio, vane dimensions, and arrangement of the submerged vane system influence the location of the saddle point thus created. Although vane length exerts no impact on the site of the saddle point formed, any increase in the height of the vanes causes the saddle point to be formed at a greater distance from the intake entry point, and the return flows to be overlooked. Furthermore, when the submerged vanes are installed at a greater transverse distance, the intake conditions improve because no flow from the downstream side transfers to the intake channel. However, the location of the formation of the saddle point is not affected by the longitudinal distance between the vanes and the angle of attack of the submerged vanes to the flow direction. Lastly, as the intake ratio increases, a saddle point is created near the intake inlet, and the return flow pours into the intake from the lower edge of the intake port [49].

5. Conclusions
The lateral intake structure is used to convey the domestic, agricultural, and industrial water, and exhibits the characteristic highly complex, three-dimensional, morphodynamic behavior. The studies reviewed were based on the lateral channel regarding the flow and physical characteristics, submerged vane theory, and the parameters and arrangement of the vanes. After the flow characteristics of a straight lateral channel were reviewed, as well as the submerged vane technique. The construction of a
lateral channel to reroute some of the water from the main flow influences both the main channel flow and river bed morphology, changing the shape of the bed, particularly at the junction zone. These fluctuations have several repercussions, including alterations in the slope of the main channel resulting from the erosion and sedimentation in the main and branch channels. When the flow has deviated to the side channel, secondary circulation takes place as the faster-moving surface water uses higher power to turn than does the slower-moving water near the bed, identical to the bend flows. In addition, the hallmark characteristic of the flow in a junction (having high erosion potential) is the production of a low-pressure region with a rotating flow (having high deposition potential) coupled with a high-velocity zone.

Vanes have been widely used to reduce the transport of bed sediment into diversions. The performance of the submerged vanes, on the other hand, is influenced by a number of factors, including their parameters and arrangement. As the flow moves past the submerged vane, the pressure head is noted to rise before the vane and fall after it, therefore, inducing a secondary flow after the vane. The secondary vortices resulting from the submerged vanes are dependent upon their arrangement, which induces changes in the speed distribution pattern, and consequently reduces the deposits and transfers the sediments away from the intake inlet. Finally, the submerged vanes system cannot provide the solution to all the problems related to river training and sediment control. Several projects will necessitate the application of many solutions.

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