# The Effect of the Side-Weir Crest Height to Scour in Clay-Sand Mixed Sediments

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***Abstract*—**Experimental studies to investigate the depth of the scour conducted at a side-weir intersection located at the $180^0$ curved flume which located Hydraulic Laboratory of Yıldız Technical University, Istanbul, Turkey. Side weirs were located at the middle of the straight part of the main channel. Three different lengths (25, 40 and 50 cm) and three different weir crest height (7, 10 and 12 cm) of the side weir placed on the side weir station. There is no scour when the material is only kaolin. Therefore, the cohesive bed was prepared by properly mixing clay material (kaolin) with 31% sand in all experiments. Following 24h consolidation time, in order to observe the effect of flow intensity on the scour depth, experiments were carried out for five different upstream Froude numbers in the range of 0.33-0.81.

As a result of this study the relation between scour depth and upstream flow intensity as a function of time have been established. The longitudinal velocities decreased along the side weir; towards the downstream due to overflow over the side-weirs. At the beginning, the scour depth increases rapidly with time and then asymptotically approached constant values in all experiments for all side weir dimensions as in non-cohesive sediment. Thus, the scour depth reached equilibrium conditions. Time to equilibrium depends on the approach flow intensity and the dimensions of side weirs. For different heights of the weir crest, dimensionless scour depths increased with increasing upstream Froude number. Equilibrium scour depths which formed 7 cm side-weir crest height were obtained higher than that of the 12 cm side-weir crest height. This means when side-weir crest height increased equilibrium scour depths decreased. Although the upstream side of the scour hole is almost vertical, the downstream side of the hole is inclined.

***Keywords*—**Clay-sand mixed sediments, scour, side weir.

## I. Introduction

A SIDE-WEIR is also known as a lateral intake structure, which is widely used in irrigation, land drainage, and urban sewerage systems for flow diversion or intake purposes. Side-weirs are used for water level control, diverting excess water into relief channels during floods, as storm overflows from urban sewage systems and as head regulators of distributaries.

A review of literature shows that rectangular sharp-crested side weirs have been investigated extensively by [1]-[4] and others. Most of the side weir flow studies are focused on the hydraulic behavior and discharge coefficient of side weirs for the different type of weirs and flow conditions. Many investigators have been interested on side-weir flow over fixed bed conditions as [5], [6]. However, there has not been sufficient investigation into the effect of side-weir flow on main flow over an alluvial channel, except for a few researchers such as [7]-[11]. Interaction of side weir overflow with bed-load transport and bed morphology in a channel had studied by [12].

Local scour around hydraulic structures is affected by a large number of variables primarily the flow, fluid, sediment and structure characteristics. The process of local scour has been investigated extensively for non-cohesive alluvial materials. Although, river beds and banks are found to be composed of mixture of bars of gravel, sand, clay and silt, frequently, little is known about the effect of the presence of cohesive material around hydraulic structures.

The scour process in cohesive, fine grained soil is different from that in non-cohesive, coarse grained soils and is not well studied, possibly because the cohesive behavior is complicated. The fine sediment particles are connected with each other as a result of strong influences of the electrochemical reaction on the surface of particles in water [13]. The scour process is significantly affected by the amount and type of minerals clay, microscopic and macroscopic clay properties, water content, pH and temperature of the eroding water, and thixotropy and consolidation of clay [14].

Many investigators such as [15]-[22] have been interested in local scour around hydraulic structures on cohesive bed conditions. Most of these researchers have studied experimentally on local scour for clay and clay-sand mixed beds. The aim of this study was to determine the effect of the side weir to the flow-scour characteristics and scour depth on clay-sand mixed beds.

## II. The Structure of the Side Weir Flow

A side-weir is an overflow weir set into the side of a channel. The first realistic approach is about the side-weir was produced by [23]. The side-weir equation is assumed for discharge per unit width as;

$$q = \frac{dQ'}{dx} = -\frac{dQ}{dx} = C_d\sqrt{2g}\left(h-p\right)^{3/2} \quad (1)$$

where; $x$ = distance from the beginning of the side weir; $h$ = depth of flow at any section, $Q$ = discharge in the main channel, $dQ/dx$ (or $q$) = discharge spilling for per unit length of the side weir; $g$ = acceleration due to gravity; $p$ = height of the side weir and $C_d$ = discharge coefficient of rectangular side weir (Fig. 1). The term (h-p) represents the pressure head

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above the side weir crest and $[2g\ (h\text{-}p)]^{1/2}$ is the approach overflow velocity [24] .

In Fig. 1, $h_1$, depth of flow on the upstream end of the side-weir in the main channel centerline (m), $h_2$, depth of flow on the downstream end of the side-weir in the main channel centerline (m), h, depth of flow at any section (m), $Q_1$, discharge in the main channel ($m^3$/s), $Q_2$, discharge in the main channel after side-weir ($m^3$/s), $Q_w$, discharge spilling of the side weir ($m^3$/s), $V_1$, mean velocity of flow at the upstream section of side weir in the main channel (m/s), $V_2$, mean velocity on downstream of side weir (m/s), $V_s$, flow velocity of spilling of the side weir (m/s), b, width of the main channel (m), L, length of the side-weir (m) and Ψ flow deviation angle .

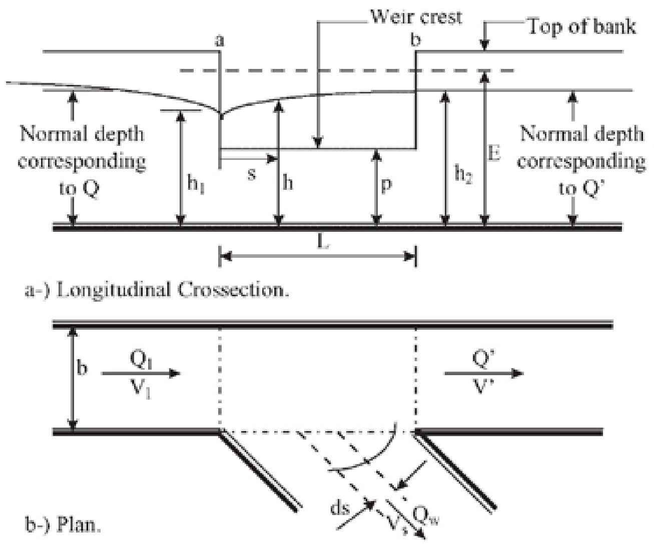


Fig. 1 Definition sketch of subcritical flow over a rectangular side weir [10]

Fig. 2 shows the simplified, spatial flow mechanism in side weir channels for subcritical flow conditions (points (1) to (3) and (5)). In addition, streamline pattern in presence of a submerged obstacle or deposit close to the weir are presented (point (4)) [12]. Zone 1 is the inflow zone, zone 2 is the lateral outflow zone, zone 3 a separation zone, zone 4 a stagnation or second separation zone and zone 5 the zone where the flow field re-establishes.

According to the one-dimensional flow theory the surface profile in side weir channels is influenced by the local Froude number, the channel and lateral outflow geometries and the up- and downstream flow conditions [25].

As can be seen from Fig. 1, the water level rises from the upstream end of the side-weir towards the downstream end in the main channel for subcritical flow conditions. However, [1], [26] have pointed out that the water level drops slightly at the upstream end of the side weir due to the side-weir entrance effect. Then the water level rises rapidly from the upstream end of the side-weir towards the mid-span of the crest and the rate of rise decreases substantially.

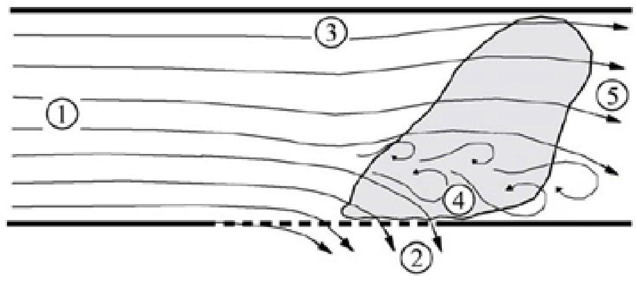


Fig. 2 Different flow zones in a channel with a side-weir [12]

The change in water level is slightly noticeable for nearly up to the last third of the weir length, where the water surface is almost horizontal. This behavior of the water surface level agrees with the explanation of the secondary flow effect due to lateral flow near the downstream end of the side-weir. The above-mentioned researchers and [9] observed the separation zone and the reverse flow at the downstream end of the side-weir in straight channels for subcritical flow.

According to these researchers, the location, size of the separation zone and reverse flow area are depend on the Froude number (Fr) at the upstream side of the weir and also on the length of the side-weir [11]. The existence of this separation zone is due to the diversion that occurs from the path of maximum velocity thread. The area occupied by this zone is always near the bed, from 0.2 to 0.4 of the mean flow depth at that section along the weir, and it varies with this area occupied by the low velocity layer [26]. The separation zone and reverse flow areas move towards the downstream as Fr increases [10].

Helpful information concerning the flow pattern in side weir channels can be derived from studies concerning lateral intake structures and open-channel diversions [27]. An analogy of flow structure at diversion channels and bend flows is assumed by [28].

## III. Experimental Set-Up and Methods

Experiments for studying the development of a scour hole around a side-weir were carried out with a model located on a rectangular Plexiglas flume at the Hydraulic Laboratory of Yildiz Technical University, Istanbul, Turkey (Fig. 3). The main and discharge flumes are located between two straight channels at a central angle of $180^0$ with 2.95 and 3.40 m radius to the centerline, respectively. The bend is connected with an upstream straight reach of 14 m and a downstream straight reach of 3 m. The main flume is 0.40 m wide and 0.55 m deep with a well-finished aluminium bottom. The discharge collection flume is 0.55 m deep, 0.50 m wide and situated parallel to the main flume with a bed slope of 0.001. Details of the flume are shown in Fig. 4.

The sediment recess was 0.11 m deep and 3 m long and located at 8 m downstream from last grid located the flume entrance (Fig. 5). Side-weirs are placed in the middle section of sediment recess. Inclined plates are placed the upstream and downstream sections of the sediment recess for flow to prevent damage. Water is re-circulated into the flume by a pump. Water is supplied from an overhead tank with a constant head and measured by a calibrated $90^0$ V-notched weir ($Q_1$) at the beginning of the main channel.

The water depth is controlled by a sluice gate located at the end of the main flume to produce the uniform flow. During the experiments, the upstream valve is adjusted slowly without causing any disturbance to the bed material until the desired flow conditions are obtained in the flume. The filter located upstream tank of the channel aided in maintaining almost constant suspended sediment concentration throughout an experimental run.

Cohesive material (kaolin) was mixed with 31% sand having $d_{50}$=1.15 mm. The experiments were carried out for determine the properties of cohesive soil in Geotechnics Laboratory of YTU, Istanbul, Turkey.

The properties of the cohesive soil were; $d_{50}$ =0.002 mm, Liquid limit, $W_L$ = 29%, Plastic limit, $W_P$ = 21.3%, Plasticity index, *PI* =7.7%, Optimum Moisture Content, 20%. As per The Unified Soil Classification System (USCS); the clay was classified as *CL* i.e. inorganic clay and silty-clay with low plasticity.

At first, the cohesive material and sand were mixed homogeneously by the help of mixer in dry condition. Sufficiently water for saturated mixture was added to the homogeneous mixture in a container. In all experiments, initial moisture content is measured 21±3%. It was well mixed before placement in the test section.

Fig. 3 Experimental system

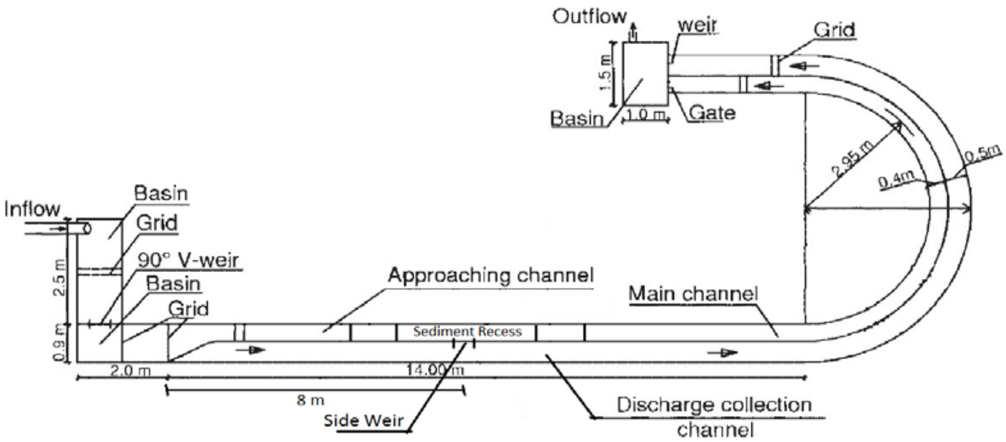


Fig. 4 Plan of test flume

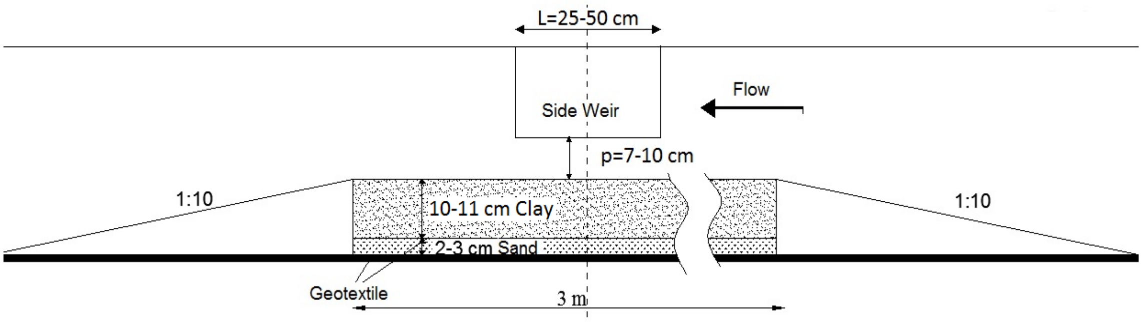


Fig. 5 Experimental Set-up

The materials have been exposed to pressure of 216 kN/$m^2$ during 24h consolidation time. After experimental run was completed, bed shear strength was measured by the vane method. The vane shear strength is a significant parameter in describing the maximum equilibrium scour depths in clay–sand mixtures [21].

For all the experimental runs, the beds were prepared afresh, by removing all material from the previous run in order to have similar degree of consolidation for different runs. Three different dimensions of side weir with a length of L=25, 40 and 50 cm and height of p=7, 12 and 17 cm were located at the experiment section.

## IV. Results and Discussion

For side weir on cohesive bed, maximum scour depth ($H_{de}$ depends on the following dimensionless parameters;

$$H_{de}/h_1 = f\left(Fr_1, C, W_c, L/b, \tau_s/[\rho.g.h_1]\right)$$

where $Fr_1$= upstream Froude Number at the beginning of the side weir in the main channel, $C$= sand content, $W_c$= initial moisture content, $\tau_s$ = bed shear strength, $\rho$= is the density of the liquid, $g$ = acceleration due to gravity.

In order to observe the effect of flow intensity or the upstream velocity in the main channel on the scour depth, experiments were carried out for different upstream Fr in the range of 0.33- 0.81 which indicate subcritical flow conditions. Each experiment was run until the variation in scour depth is almost zero. As seen from Fig. 5, the depth of scour increases rapidly with time at the beginning, and then asymptotically approaches stable values in all experiments as in non-cohesive material. That means that the scour depth reaches an equilibrium condition. Time to equilibrium depends on the approach flow intensity and the dimensions of side weirs. When the flow intensity increases, time to the equilibrium depth of scour increases but it could be changed with side-weir dimensions. In the other words, when Froude number or the flow intensity increases, the equilibrium depth of scour increases Fig. 6.

In Fig. 7, $H_{de}$ and $H_d$ represents respectively equilibrium depth of scour and the depth of scour at a particular time, t, and $t_e$ represents time to equilibrium depth of scour. Fig. 7 shows the temporal development of the scour hole plotted as $H_d/H_{de}$ versus $t/t_e$ together with flow intensity as a parameter for L/b=1 and p=10 cm. It shows a family of curves with increasing flow intensity ratio in the direction of increasing scour depth or decreasing time.

For these side-weir dimensions, the data indicates that 85-90% of the equilibrium depth of scour is attained during a time period 20% of $t_e$ for larger Froude Numbers and 80% of the equilibrium depth of scour is attained during a time period from 30 to 55% of $t_e$ for smaller Froude Numbers.

Fig. 8 shows dimensionless equilibrium scour depth ($H_{de}/h_1$) versus Froude number together with the side weir crest height as a parameter. For different heights of the weir crest, dimensionless equilibrium scour depths increases with increasing upstream Froude number. Equilibrium scour depths which formed 7 cm side-weir crest height were obtained higher than the others. This means when side-weir crest height increases equilibrium scour depths decrease. Side weir crest height was determined to be more effective parameter on scour than side weir length for these experiment conditions.

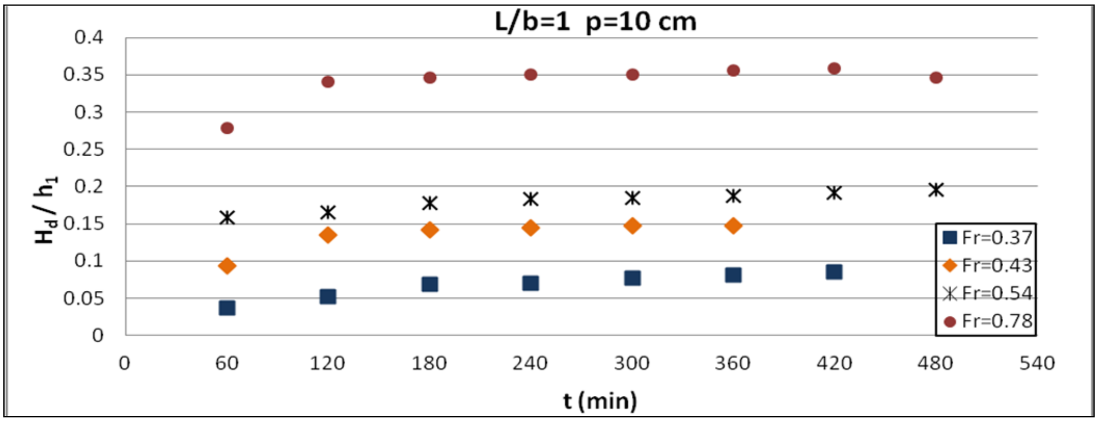


Fig. 6 The effect of upstream flow intensity as a function of time to scour depth

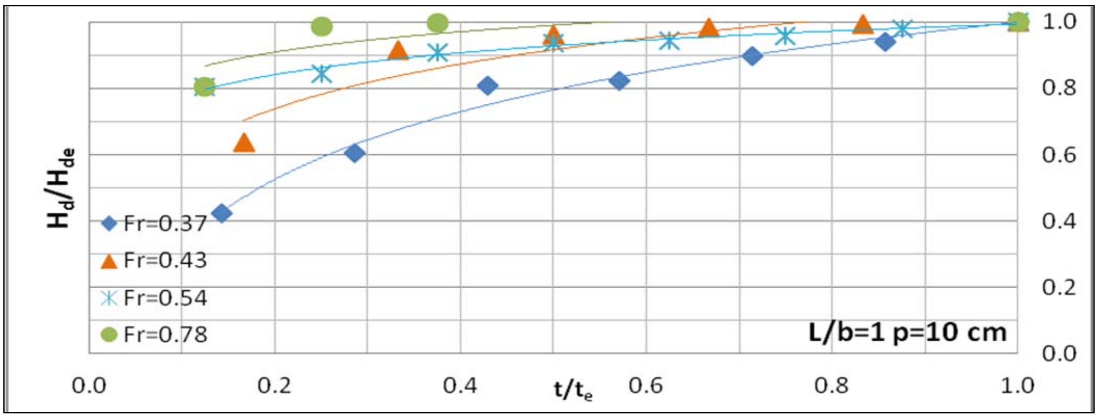


Fig. 7 Temporal development of scour depth with time for L/b=1 and p=10 cm

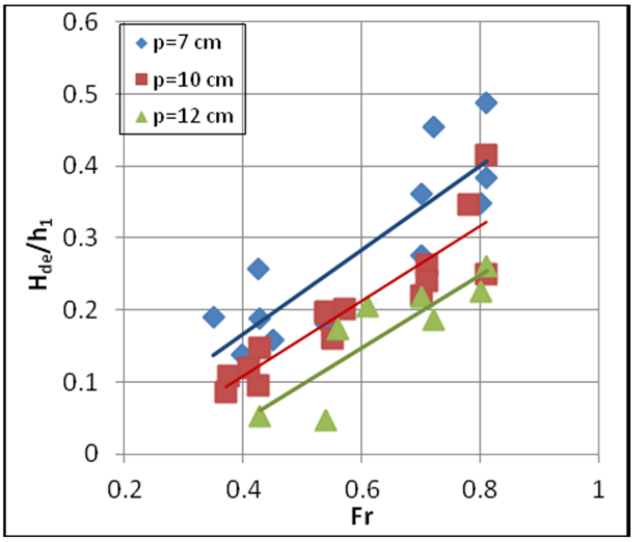


Fig. 8 Temporal development of scour depth with time

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